

CERAMIC TECHNOLOGY

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THE POTTERY GAZETTE

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CERAMIC TECHNOLOGY

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CERAMIC TECHNOLOGY

BEING

SOME ASPECTS OF TECHNICAL SCIENCE
AS APPLIED TO POTTERY
MANUFACTURE

EDITED BY

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PHILADELPHIA

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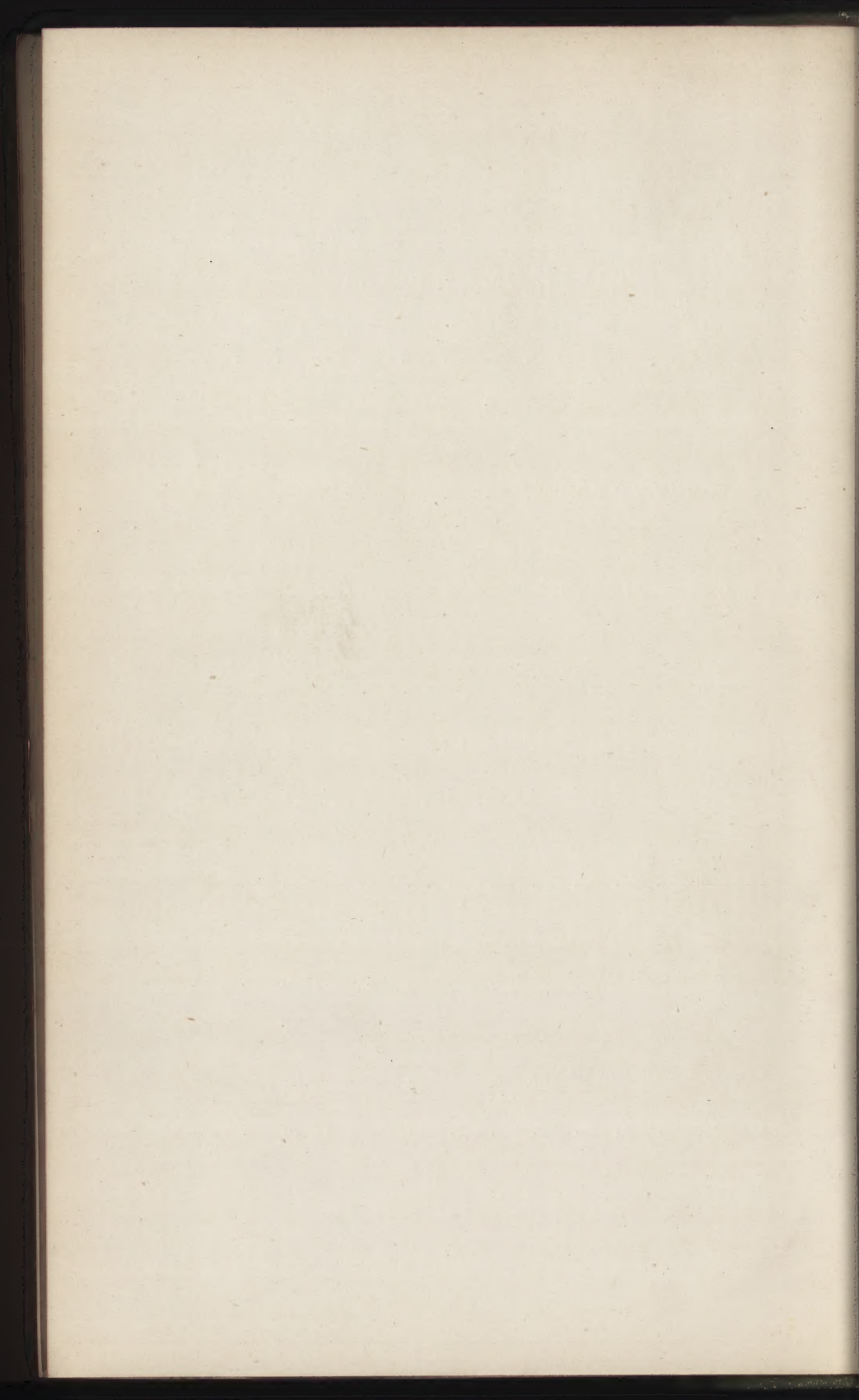
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PREFACE.

IN compiling this work the publishers have endeavoured to keep clearly before them the purpose of assisting, in as simple and intelligible a way as possible, those who desire to attain to some fuller understanding of the manifold problems of the Potter.

The book is, confessedly, imperfect. Science is making rapid strides, and to keep pace with these is no easy task.

Since the days of Simeon Shaw nothing dealing with the technical science of pottery has been published in England, and the proprietors of the *Pottery Gazette*, in offering the present work to their clients, feel that, while they could not refrain from making a beginning, it is only a first step that has been taken.

The authors wish to express their indebtedness to the published works of Brogniart, Salvétat, Seger, Langenbeck and Percy, and also to the pages of *Die Thonindustrie Zeitung* and the Handbook to the Pottery in the Geological Museum.

They have attempted to gather and sift scientific information from every possible source, and if they have used any such without acknowledgment they can only crave absolution.

Much, after all, depends upon the use that is made of knowledge. To a wise man a hint is sufficient, and it is hoped that those who read this volume will find somewhat whereby to profit.

Strict scientific terms have been purposely avoided. To the learner they often cause confusion, to the learned they are unnecessary, so that those who are disposed to smile at what they regard as the simplicity of the writers are entreated to remember that all men are not equally wise.

19 LUDGATE HILL,
July, 1897.

INTRODUCTION.

THE advances made in technical education during recent years, more especially in Germany and the United States, render it imperative that Great Britain should be roused to an appreciation of the fact that her commercial position is seriously assailed.

It would have been possible a few years ago to assert that the British workman was still supreme, but in an authoritative publication it is stated that "the great industries of to-day depend more and more upon the successful application of recent discoveries to ordinary manufacturing processes, and less and less upon the presence of coal, iron, and raw materials. Cheaper and more speedy means of transit are placing all countries more nearly on a level as regards natural resources. Improved tools and labour-saving machinery are rapidly rendering the manual skill and dexterity of the individual workman of minor significance, and in the industrial race in which all are engaged nearly all the advantages upon which Great Britain prided herself in the past are possessed in a greater or less degree by her rivals, and count for little as

compared with scientific knowledge and its ready application to the needs of the manufacturer." * These are wise words, and it will be well if they are laid to heart by all who are interested in the commercial welfare of this country and her inhabitants. Germany long ago made strenuous efforts for the complete scientific and technical education of her people, and so far from relaxing those efforts to-day she is continually exerting all her powers in the same direction.

From the United States comes the report that at one of the Universities a class in ceramics has been established with the view of turning out, after a two or a four years' course, men competent to take charge of any department in practical potting. These things evidence the opinion fixed in the minds of all thoughtful men that education is the foundation of progress.

Potters in England are not, perhaps, worse than other manufacturers, except that in their particular work there is unlimited scope for the operations of science, but it is to potters that these lines are addressed and therefore their shortcomings are more especially alluded to.

In former years a certain monopoly of enterprise and skill founded and extended the Stafford-

* Report on a visit to Germany with a view of ascertaining the recent progress of technical education in that country. London: Eyre & Spottiswoode, 1896, p. 10.

shire potteries, but the path was thus made clear to any one who wished to follow it, and however complete may have been the monopoly in the past it has most certainly been broken down. The competitor, excellently trained, and provided with all the resources of modern science, has come to the front, and, incredible as it may seem, the British Parliament has, in the Merchandise Marks Act, afforded him abundant advertisement free of charge.

It may not be possible for England to regain a monopoly, from the consumer's point of view it may not even be desirable; but it is not yet too late for British manufacturers to arise and, by a development of the powers which they undoubtedly possess, to smite the foe with a great discomfiture.

It would appear, at first, to be necessary to arouse those who think, to the importance of education, and it is partly for this purpose that this book has been published. It is hoped that by a perusal of its pages some may be led to understand that, even if they do not agree with what has been written, there are at least two sides to the question. But in the present state of rivalry existing amongst potters, what possibility is there of discussion? What likelihood is there that a well-conceived and unanimously supported scheme of advancement will be formulated? The require-

ment seems to be, as a preliminary, a central research laboratory, to which any accredited person may have access, and where may be duly published the results of investigations. It would not be difficult for any practical potter to put two or three questions, the examination of which would keep an investigator at work for months, and of which the satisfactory solutions would be the means of saving large sums of money to the potting industry. At present the rivalry of trade seems to prevent any one seeking the advice of a possible competitor, and until the initiative is taken by some executive authority there will be but little hope of progress.

The old days of *laissez faire* are passing away. Every competing nation is keenly alive to the necessity for education, and England must not be the last.

The problems of profitable potting are numerous and important, and if they cannot be solved single-handed English potters must combine for their mutual benefit.

An attempt, however imperfect, has been made in the present volume to throw light upon some difficulties, in the ardent hope that the day may soon dawn when the troubles and losses which now cling as a nightmare to the shoulders of the ceramic industry of Great Britain shall vanish as a dream.

CERAMIC TECHNOLOGY.

CHAPTER I.

THE CHEMISTRY OF POTTERY.

CHEMISTRY is the science which deals with the composition of substances rather than with their condition. It also defines the relationship in which one substance stands to another and governs their mutual reactions.

The ceramic chemist has, however, almost as much concern with physical as with chemical laws, inasmuch as he is face to face continually with the effects and operations of fire.

The success of the potter depends largely upon the skill with which he can combine his materials so that they may yield him the result for which he strives and may do so with the smallest possible loss. This skill should be founded upon expert knowledge, which is, after all, only another term for science.

Much has been said and written upon chemistry as applied to pottery, which, to the average

manufacturer, is perfectly useless by reason of the fact that the authors assume a degree of information not possessed by the reader. The attempt will be made here to avoid this error in the belief that it is better, all things considered, to be too simple than to be too abstruse.

Chemical knowledge is of use to the potter throughout the whole of his operations. It controls the mixtures of his body, glaze and colour, the purity of his materials, and the composition of gases in his kilns. It will enable him to lay his finger upon weak points and to arrest losses, besides putting into his hand a new power of producing combinations hitherto unknown.

An attempt will be made in the present chapter to indicate the functions of the materials in general use, and some of the more simple empirical tests will be alluded to. Chemical analysis is not always within the reach of the manufacturer, and, even if it be available, it either teaches nothing or it teaches too much. To take advantage of the story of an analysis other things must be taken into account, and it is hoped that what is said here will prove of practical value.

I.—MATERIALS.

Ceramic composition is a matter of compromise. Certain constituents in a body are

plastic, certain are "short". Others are easily melted, others again are infusible. It is the judicious combination of these qualities that makes the best mixture.

At the head of the materials used by potters all over the world china clay (kaolin) and china stone (petuntse) stand supreme. Geologists have not yet accurately determined the relations between these two substances, but that the clay is in some sort dependent upon the stone is almost generally accepted.

The pure form of kaolin would be a silicate of aluminium,* but in practice this does not exist. Mechanically associated with it are minute portions of foreign substances, quartz, lime, alkalies, and occasionally a little magnesia. The potter has usually nothing to do with the preparation of the clay. It comes to him ready for use. It is, at the same time, important that every consignment should be properly sampled, and instructions on the best methods of accomplishing this will be found in the chapter on clays.

Petuntse or Cornish stone needs a somewhat different method of testing. The quality varies

* The pure hydrated silicate of aluminium has been named by Messrs. Johnston and Blake "kaolinite," and is assumed to be the basis of all clays. It corresponds to the formula $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 + 2\text{H}_2\text{O}$.

considerably, and for many years a stone much harder to break and softer to fire has been extensively used. The main difference between this and the yellow crumbling stone is in the amount of alkalies contained. It is probable that all the stone was once in the hard blue state, but the action of water has resulted in a partial decomposition and solution of the combined alkaline salts. These being washed away the stone begins to disintegrate, and it is found that the loss of alkali ranges from 3 to 4 per cent., or even higher. This, of course, constitutes a serious difference in the fusibility of the stone, and each new consignment of each kind of stone should be carefully tested. The main points to be considered are fusibility and colour. A small piece of the stone fired at top biscuit heat should show very few of the hard yellow particles so often found, and the felspathic parts should have melted almost clear. A portion of the stone may also be finely ground and mixed with a little clay. Of course a definite quantity of both stone and clay must be taken. This can then be cast or pressed into small cups for firing in the biscuit oven. The translucency of the fired mixture will afford a good criterion of the fusibility of the stone. All fire tests are, however, useless unless the degree of heat can be ascertained and uniformly adhered to. For this purpose there

is nothing better than the pyrometric cones, to be presently dealt with.

Bone is a material that is more easily tested in the sample than in the mixture. It may be taken as a general rule that the best bone is the cheapest. Bone ash usually contains a considerable proportion of foreign matter, and this not only displaces a certain amount of the bone which should enter the mixing tank, but also exerts a deleterious influence upon the body, both in the matter of colour and fusibility. A rough and ready test as to the comparative values of coarse and fine bone may be readily made by sifting a small quantity through a fine sieve and then mixing two trials of body clay, using in one case the coarse bone, and in the other the fine. The body mixed from the fine bone will be neither so white nor so hard as the other. Thus, though the first cost of good unbroken bone be greater, the ware made with it is much better, and there is less oven loss.

Felspar and flint are both fairly uniform in character and composition, and when any momentous change takes place in the quality of a consignment, the appearance of the raw material will indicate it. But some manufacturers purchase ground spar and flint, and to such it must be important to secure purity. Any deleterious sub-

stance in the flint may readily be detected by simply firing a small portion in the highest available heat. If the flint stand this without sign of fusion it is suitable for any purpose. Fired at the heat of china biscuit oven, pure spar should melt down almost to transparency. It should exhibit a pearly white colour and be entirely free from spots.* The effect of spar in a mixture may be tested in the manner described for stone. To a pure china clay felspar will impart translucence at a sufficient heat, and the colour of the mixture and amount of fusion will at once indicate the quality of the material.

II.—MATERIALS IN COMBINATION.

A knowledge of the function fulfilled by each material in a mixture is of the highest importance to the practical potter. Without this knowledge all his work is more or less hap-hazard, and success is more a matter of good luck than good guidance. A pottery "body" exhibits a very close analogy to the body of a living creature in that its several constituents fill the position of flesh, blood, and bones. The flesh is, of course, the clay. This

* It will, of course, be understood that the tests spoken of here are only those that could be readily undertaken in an average manufactory. Where doubt exists as to purity a chemical analysis should be made.

it is which gives texture and mobility. This enables a mixture to be called a "body" at all, and gives it form and feature. The bones are supplied by the actual bone in porcelain or by flint in earthenware, the former being chosen on account of the stiff infusibility which gives to porcelain its framework and enables it to stand the fierce fire. The functions of the blood are fulfilled by the fusible ingredients, stone or spar. These give life, translucency, vitrification, ring, and fracture. It is these that give to a body its quality and superior nature. These fusible ingredients melt, and flow through the particles of flesh and bone, uniting them into one, and endowing them with a living personality.

It is essential then that these three principles should be combined with due regard to their special offices. The clay, whether as kaolin or ball clay, will constitute the working properties. Clay is not altered in the fire beyond the fact that its water of combination is driven away, but the fire leaves it in a porous state, and this porosity must be overcome, at least to some extent, by the addition of fusible matter. Without such addition the clay will exhibit no strength or quality, its fracture will be similar to that of a tobacco-pipe, and it will be ill fitted for hard wear. Either stone or spar will supply the

necessary flux. In the former case a larger proportion will be needed, as the percentage of alkali is smaller, and it is this alkali—usually potash—in both stone and spar which does the work.* According, then, to the amount of vitrification needed the fusible material is added, but the presence of the alkali immediately calls for a corrective. It is of the highest importance that the potter's work should maintain its shape in the fire, and this it will not do if the softening effect of the flux remain unchecked. For earthenware and so-called semi-porcelain flint will serve. The silica of which this is composed is infusible at low temperatures, and besides the dense nature of the flint itself helps in the strength of the body. For higher temperatures bone is generally used. Upon the intense fire the quality of porcelain depends, and, therefore, it is necessary to render the body sufficiently stiff to stand a severe heat. This the bone does, and, while it upholds the ware, the fire drives the fluxing influence of the potash in stone or spar through the whole mass of the body, giving quality, character, and translucence. While this is the function of bone, and indicates its relationship towards the other constituents of the body, there

* In practice it will be found that to equal 100 parts of stone it is necessary to take 34 parts of spar, 31 of china clay and 35 of flint.

are, of course, in the structure of the bone itself certain advantageous features. The cellular form of the animal organism is not entirely broken down in grinding, and this imparts to the porcelain the lightness which is so greatly valued. Pure bone is also very white, perhaps the whitest of all the materials used, and this must be considered an important advantage. To what extent these combinations of materials are subject to chemical laws is as yet but imperfectly understood. The fact that all the reactions take place in the glowing recesses of the oven renders them extremely difficult of investigation, and the apparent impossibility of securing absolute uniformity of conditions, time after time, for the purpose of continuous experiment, renders the work of the scientific potter tedious and inconclusive. Experiments are often misleading, but, at the same time, every search for light must begin in the laboratory. The investigator must be prepared for disappointment, and must, with inexhaustible patience, subject his ideas to the test of time, and tabulate his results by means of a long series of averages. Experimenting in pottery is costly work, but without it there can be no possibility of progress.

CHAPTER II.

ANALYSIS AND SYNTHESIS.

I.—ANALYSIS.

As a preliminary step to a complete knowledge of his material, the potter should make himself thoroughly acquainted with the chemical composition of each one. Without this knowledge an elaborate analysis teaches him nothing, and he is unable to keep touch with the variations constantly occurring in every substance that he uses. In other chapters will be found some particulars as to the function and testing of clays and other materials, but here it is proposed to sum up the scientific researches of ceramic chemists in various parts of the world by giving in tabulated form analyses of clays and rocks, followed by those of bodies compounded in every country. It has not been thought necessary to name the author of each analysis. Let it suffice to say that the figures given are all from trustworthy sources.

1. Kaolin* or China clay is found in many parts of the world; the English supply coming from Cornwall (hence the name "Cornish clay"). It undergoes a considerable amount of preparation at the place of origin, and is delivered at the manufactory ready for use. Kaolin is called by geologists a "primary" clay because it is in the condition of original deposit. It will be seen from the analyses given that the average amount of impurity in the clay is very small.

KAOLIN.

	Silica.	Alu- mina.	Lime.	Alkalies.	Mag- nesia.	Ferric Oxide.	Water.
English -	47·96	38·29	·43	·56	...	·90	12·76
" -	47·10	37·33	·14	·20	·47	1·11	13·45
" -	48·11	36·77	1·50	1·50	·54	·44	11·80
" -	43·32	39·74	·36	...	...	·27	12·67
" -	46·38	38·60	3·47	1·77	trace	...	9·08
" -	45·52	40·76	2·17	1·90	trace	...	9·61
German -	46·87	38·56	trace	·06	trace	·83	12·73
American -	46·47	38·82	·28	·75	·25	·89	13·34
" -	47·66	37·56	·20	·25	·36	1·39	13·47
" -	48·50	38·31	·10	·76	·14	·59	12·24
" -	46·47	38·82	·28	·48	·25	·89	13·34
" -	46·13	39·17	·22	·40	·30	1·00	13·10
" -	45·22	39·11	...	·97	·28	1·21	13·20
French -	48·00	37·00	...	2·50	...	...	13·10
" -	49·00	36·00	...	1·60	...	...	12·60
" -	48·00	36·00	...	2·00	...	...	13·00
Chinese -	50·50	33·70	...	1·90	...	...	11·20

Next in importance to Kaolin and closely

* The term Kaolin is said to be derived from *Kaouling* (lofty ridge), the name of a hill in China from which some of the substance was obtained. *Geolog. Mus. Handbook.*

related to it is stone or Cornish granite (named by the Chinese "Pe-tun-tse," and by mineralogists "Pegmatite"). It will be seen that this differs from Kaolin in that the proportions of silica and alkalies are much larger, rendering the substance more fusible and less plastic. Stone is liable to very great fluctuations in composition, as will be seen from the analyses given.

CORNISH STONE.

	Silica.	Alu- mina.	Lime.	Mag- nesia.	Iron.	Fluo- rine.	Alka- lies.	Water.
English - -	73.39	16.50	.50	.31	trace	.74	7.66	1.25
" - -	69.50	17.85	2.66	.12	...	.71	7.98	1.30
" - -	71.66	18.79	1.70	.35	...	.14	6.60	.91
" - -	73.57	16.47	1.17	.21	.27	...	5.84	2.45
" - -	72.99	17.58	1.25	.37	.15	...	6.20	1.77
" - -	74.55	17.37	1.68	.54	.26	...	3.68	2.04
" - -	73.77	16.05	1.14	.22	.23	...	7.52	1.78
American (Texas)	68.88	16.77	.99	.17	.83	...	6.77	5.79
Chinese (Yaou-ko)	75.90	13.90	.40	trace	.70	...	5.17	2.7
Limoges - -	74.30	18.30	.40	.30	...	...	6.50	.30

To the earthenware manufacturer Ball clay is of the highest importance. This is termed by geologists a "secondary" clay, inasmuch as it is believed that the deposits are not in their original condition, but have been washed up and redeposited or, possibly, derived from the decomposition of stratified rocks as the primary clays are from crystalline.

BALL CLAY.

	Silica.	Alu- mina.	Lime.	Mag- nesia.	Iron.	Alkalies.	Water.
Teignmouth	52.06	29.38	.43	.02	2.37	2.29	12.70
Poole - -	48.99	32.11	.43	.22	2.34	3.31	11.60
Florida -	45.39	39.19	.51	.29	.45	.83	14.01
New Jersey-	46.18	39.08	.42	.35	1.11	.51	13.04
Missouri -	48.51	35.18	1.01	1.47	.92	2.30	10.72
Strasbourg -	66.70	18.20	...	.60	1.60	...	12.00
Echassières-	49.20	34.00	...	...	...	...	16.40

It will doubtless be noticed that some of these analyses differ only in minute degree (except as to the iron and alkalies) from Kaolin itself, and it is difficult to say why these clays should be so much stronger and more plastic than Kaolins. Perhaps the fact that Kaolin is manipulated and prepared after mining has something to do with its comparative lack of tensile strength.

Fire clay, otherwise called Stourbridge clay or Marl, is largely in demand on account of its fire-resisting properties. The potter is dependent upon it for his supply of saggers and, naturally, looks to the refractory nature of the clay to diminish his losses. It must, however, be remembered that infusibility is not the only quality to be sought for. Saggers must bear great weight, and are exposed to rapid influences of heating and cooling besides coming directly into contact with the disintegrating action of the flames and kiln gases. Unfortunately an analysis does not afford much real indication of

the lasting qualities of a fire clay, because so much depends upon mechanical structure and, perhaps, still more upon preparation.

FIRE CLAY.

	Silica.	Alu- mina.	Lime.	Mag- nesia.	Iron.	Alka- lies.	Water and Organic Matter.
English (Stourbridge)	65.10	22.22	.14	.18	1.92	.18	9.86
" (Brierley Hill)	51.80	30.40	1.46	.50	4.14	...	13.11
" "	51.10	31.35	1.34	1.54	4.63	...	10.47
" "	47.55	29.50	1.66	.71	9.13	...	12.01
" "	48.55	30.25	1.76	1.91	4.06	...	10.67
" "	51.11	30.40	...	trace	4.91	...	12.29
" "	72.28	17.75	...	2.30	2.43	...	6.94
" "	83.29	8.10	...	2.99	1.88	...	3.64
" "	69.25	17.90	...	1.30	2.97	...	7.58
United States - -	74.93	17.19	.29	.46	.79	1.61	5.44

The felspar most usually employed in pottery is known mineralogically as orthoclase,* and entering largely into the composition of pegmatite, is generally considered to be the parent of Kaolin. Chemically, orthoclase is a double silicate of aluminium and potassium, but small quantities of foreign substances are found associated with it from time to time. It will be seen from the analyses that its composition is fairly uniform; and, as the fusibility of the spar depends upon the contained alkali, an analysis may be considered an accurate test of quality.

* A term arising from the existence, in the mineral, of two cleavages, at right angles to each other. *Geo. Mus. Handbook.*

FELSPAR (ORTHOCLASE).

	Silica.	Alu- mina.	Potash.	Soda.	Lime.	Mag- nesia.	Iron.	Water.
German spar -	64.32	19.41	12.90	2.10	...	.35	.14	...
" " -	65.24	18.57	14.02	1.25	.34	.10	...	...
Swedish " -	65.85	19.32	14.10	...	.56	.08	.24	...
Scotch " -	65.40	19.04	11.26	3.63	.22	...	trace	.20
French " -	64.00	20.56	14.99	...	.38	...	...	...
Spanish " -	62.06	19.61	16.07	...	.38	.16	...	1.11

A variety of felspar, of which the base is not potash, but soda, is occasionally used. It is named "Albite" by mineralogists, and its composition is as follows :—

	Silica.	Alu- mina.	Potash.	Soda.	Lime.	Mag- nesia.	Iron.
"Albite" or Soda spar	66.81	21.09	...	9.64	2.03	.10	.13
" "	68.82	19.75	...	9.15	1.64	.17	...
" "	68.00	20.00	.68	10.88	.35	...	...
" "	67.63	20.48	...	10.26	.65	...	...

Flint and bone are the principal remaining materials in use, but, as the first is practically pure silica, and the second should be nearly pure calcium phosphate, it will be unnecessary to give analyses. Some particulars as to the behaviour of all the materials in combination will be found upon another page. It is now proposed to place before the reader a series of analyses of notable bodies of every description, which will illustrate the uses to which the materials have been put, and, perchance, open up new fields to the scientific potter.

At one end of the ceramic scale will be found the rude wares produced in ancient times by the majority of savage tribes, and at the present day by such peoples as the Egyptians and Algerians ; following upon these will be given certain analyses representing an advance in knowledge until the perfection of hard porcelain is reached. Some clue as to the origin of each ware will be found in the first column.

	Silica.	Alu- mina.	Iron.	Lime.	Mag- nesia.	Water.	Carbon.
Scandinavian pottery	63.90	12.76	10.24	1.04	.52	9.98	1.02
Peruvian "	67.04	10.83	10.17	3.24	.28	7.07	1.00
Etruscan "	64.00	12.51	8.00	3.51	1.83	8.15	2.00
Samian ware - -	64.00	17.77	10.23	4.86	"	2.23	"
Egyptian " - -	81.00	13.50	1.00	3.00	"	1.90	"

From the presence of water and carbon it will be seen that these wares have been fired at a very low temperature.

The next series consists of ware of the same class, but as both the water of combination and the carbon have been expelled, a greater heat is indicated.

	Silica.	Alumina.	Iron.	Lime.	Magnesia.
Early French - -	70.27	14.17	10.29	1.49	.98
Roman - - -	56.00	25.00	7.00	9.00	2.00
Greek - - -	55.49	19.21	16.55	7.48	1.27
Greek - - -	60.00	13.63	19.00	5.91	1.46

The bodies in the next range contain large quantities of calcium carbonate, and it will be seen that these wares were uniformly coated with opaque tin glazes. M. Salvétat states that the calcium carbonate was introduced "to give to the glaze rendered opaque by tin the resistance necessary for culinary uses," and adds that this same quality "could have been obtained by many other means, such as the employment of alkaline fritts, but it is evident that the addition of lime was the most economical".

The presence of large quantities of carbonic acid indicates that the fire could not have been a severe one, as had the silica been enabled to combine with the calcium all the carbonic acid would have been liberated and, in all probability, the body would have melted and effervesced.

	Silica.	Alu- mina.	Lime.	Mag- nesia.	Iron.	Carbonic Acid.
Luca della Robbia -	49.65	15.50	22.40	.17	3.70	8.58
Majolica - - -	48.00	17.50	20.12	1.17	3.75	9.46
Early Spanish -	46.04	18.45	17.64	.87	3.04	13.96
Delft - - -	49.07	16.19	18.01	.82	2.82	13.09
Persian - - -	48.54	12.05	19.25	.30	3.14	16.72
Nevers - - -	56.49	19.22	14.96	.71	2.12	6.50
Rouen - - -	47.96	15.02	20.24	.44	4.07	12.27
Paris - - -	61.50	12.99	16.24	.15	3.01	6.10

As quality improved, it was found that the wares contained more or less alkali, while still in some cases retaining the lime and magnesia. The iron

generally diminishes in quantity, remaining high only in the darker coloured examples, and as a consequence the paste becomes harder and capable of enduring a greater heat. The colour also is sensibly lighter, and the opaque tin glaze is no longer indispensable. It will be seen that there is no very great difference between the English and foreign wares of this description.

	Silica.	Alu- mina.	Lime.	Mag- nesia.	Iron.	Alkalies.
Palissy - - -	67·50	28·51	1·52	...	2·05	traces
D'Oiron - - -	59·10	40·24	...	...	...	...
Lunéville - - -	67·39	16·00	13·16	1·02	2·01	traces
St. Amand - - -	75·00	22·10	·25	...	1·00	·84
Oreil - - -	66·10	32·20	·14	...	·55	1·10
English - - -	76·10	20·45	·75	·14	1·00	1·60
" - - -	72·60	24·10	...	...	1·10	2·20
* " - - -	74·00	22·04	·60	·17	2·00	1·06
* German - - -	74·00	19·00	·62	...	4·25	1·30
Chinese - - -	62·00	22·00	·50	trace	14·00	1·00
Japanese - - -	62·04	20·30	1·08	trace	15·58	trace
American - - -	67·40	29·00	·60	...	2·00	·60
Staffordshire - -	66·49	26·00	1·04	·15	6·12	·20

* Salt glazed stoneware.

The distance separating these hard earthen-wares and stonewares from true porcelain is not a great one. Purer clays are, of course, used, as shown by the diminished amount of iron. In the Sèvres pastes M. Salvétat, who made the analysis, explains that the lime was purposely added to prevent crazing, and that he had always found that the addition of a small quantity of chalk to the

body cured this defect. The large proportion of magnesia in the pastes of Worcester and Piémont seems to point to the use of steatite. The alkalies evidently owe their presence to the use of felspar or Cornish stone.

Porcelains.	Silica.	Alumina.	Lime.	Magnesia.	Iron.	Alkalies.
China - - -	69.00	23.60	.30	.02	1.20	6.20*
" less fine. - -	70.00	22.20	.80	trace	1.30	6.30*
Japan - - -	78.80	17.80	.20	...	.60	2.20†
Meissen - - -	58.50	35.10	.30	trace	.80	5.00
Vienna - - -	59.60	34.20	1.70	1.40	.80	2.00
Berlin - - -	64.30	29.00	.30	.45	.60	3.65
Limoges - - -	70.20	24.00	.70	.10	.70	4.30
Sèvres - - -	58.00	34.50	4.50	...	...	3.00
Sèvres biscuit, 1838 -	67.17	26.01	3.02	.01	"	3.09
Worcester - - -	82.00	9.10	1.30	7.40	...	...
Paris - - -	71.20	22.00	.80	...	.80	4.50
Piémont - - -	69.80	10.40	2.00	17.60	...	...
Bristol - - -	62.92	33.16	1.28	...	...	2.64

* Mainly potash.

† Mainly soda.

For the sake of comparison with the foregoing hard paste porcelains there are appended a few analyses of early soft pastes. These are now considered out of date, but their luscious tenderness of paste and glaze has never been surpassed. It will be noticed that these mixtures are wonderfully low in alumina, and it is a matter of surprise that with this infinitesimal portion of clay the body should have been at all workable. The large proportions of lime and alkalies denote a low fusing-point. It will be seen that in the pastes of Chelsea and Bow, bone was used in considerable quantity.

	Silica.	Alumina.	Lime.	Mag- nesia.	Iron.	Alka- lies.	Phos- phoric Acid.
Sèvres - -	72.00	3.00	15.00	trace	...	8.10	...
" - -	78.36	1.00	12.73	trace	...	6.46	...
" - -	77.00	1.20	16.36	trace	...	5.40	...
Tournay -	76.45	7.35	11.20	trace	...	5.00	...
Chelsea -	40.20	8.40	27.40	...	1.20	1.90	20.30
Bow - -	40.00	16.00	24.00	...	...	1.90	17.30

II.—SYNTHESIS OR THE RECOMPOSITION OF MIXTURES FROM ANALYSES.

An elaborate analysis is of little use unless those who consult the figures are capable of reversing the operation gone through in analysing, thus reproducing in as accurate a form as possible the original recipe. Fortunately to achieve this it is only necessary to have recourse to figures, and thus the practical potter can avail himself of the researches of the chemist should he desire to do so.

The principle upon which this conversion is accomplished is that every substance has its own combining or equivalent weight, a definite weight representing the proportionate amount of work done by the substance itself. This combining weight is founded upon the molecular weights of the respective elements contained.

Taking then the items in an analysis one by one, each is divided by its own combining weight in order to reduce the whole to an equal basis.

For example, if the analysis of Sèvres porcelain given on page 19 be taken, the procedure would be as follows :—

Silica	$58.00 \div 30 = 1.933$
Alumina	$34.50 \div 51 = 0.676$
Lime	$4.50 \div 28 = 0.160$
Alkalies	$3.00 \div 44 = 0.068$

Here the figures in the second column are the respective combining weights of the constituent substances, and the third column gives as quotients the equivalent amount of each. In the case of mixed alkalies as above a compromise must be made between potash and soda. The combining weight of potash is 47, of soda 31, the mean being therefore 39. When, from the nature of the case, potash appears to predominate, the combining weight will be higher than the mean, and of course when soda is the greater, the reverse. Now in the case of the Sèvres porcelain under consideration either potash-felspar or Cornish stone would be used, and therefore the balance is placed in favour of potash.

Then the substances being reduced to their equivalence the operation may be continued.

The first point to be dealt with is the alkali, which must be taken, as already mentioned, either in the form of felspar or stone. On account of the variable composition of the latter it will be found

preferable to employ the spar. Each equivalent of felspar contains one equivalent of alkali, mainly potash, one of alumina and six of silica. It is necessary from the figures arrived at to take 0.068 equivalent of alkali, and with this must perforce be taken the same amount of alumina and $0.068 \times 6 = 0.408$ equivalent of silica. The amount of alumina required must now be made up by kaolin, which contains two equivalents of silica to each one of alumina. There is required altogether 0.676 equivalent of alumina, but of this 0.068 equivalent has already been taken in the spar. The remainder, therefore, $0.676 - 0.068 = 0.608$, will give the amount of kaolin. Again, in this kaolin must be taken $0.608 \times 2 = 1.216$ equivalents of silica, which, added to the amount taken in the felspar, will be $1.216 + 0.408 = 1.624$. The whole amount of silica required is, however, 1.933 equivalents, which will leave $1.933 - 1.624 = 0.309$ to be supplied. This can be given in pure form as ground flint.

There now remains only the lime, which can be dealt with simply by adding 0.160 equivalent of either marble, chalk, or whiting, which are all pure calcium carbonate, each equivalent of calcium carbonate containing one equivalent of calcium oxide.

The formula will therefore stand thus :—

Felspar	.	.	.	.	.	0.068
Kaolin	.	.	.	.	.	0.608
Flint	.	.	.	.	.	0.309
Whiting	.	.	.	.	.	0.160

In order to bring these amounts to figures that can be utilised, the combining weights of these new substances must be employed and each equivalent weight multiplied by the respective combining weight.

The combining weight of felspar is 278.4, of kaolin 129, of flint 30, and of whiting 50. The figures will therefore work out thus :—

Felspar	.	$0.068 \times 278.4 = 18.77$	parts by weight.
Kaolin	.	$0.608 \times 129 = 78.43$	" "
Flint	.	$0.309 \times 30 = 9.27$	" "
Whiting	.	$0.160 \times 50 = 8.00$	" "

As a second example it will be well to take a body in which bone has been used. The analysis of Bow porcelain given on page 20 will serve. This is :—

Silica	.	.	.	$40.00 \div 30 = 1.333$
Alumina	.	.	.	$16.00 \div 51 = .313$
Lime	.	.	.	$24.00 \div 28 = .857$
Alkalies	.	.	.	$1.90 \div 44 = .043$
Phosphoric Acid	.	.	.	$17.30 \div 71 = .243$

As in the previous analysis, the combining weight of each substance is placed in the second column and the resulting equivalent in the third.

Proceeding as before, in order to supply the

alkalies there must be taken $\cdot 043$ equivalent of felspar, which will contain also $\cdot 043$ equivalent of alumina and $\cdot 043 \times 6 = \cdot 258$ equivalent of silica. To make up the required amount of alumina there must now be taken $\cdot 313 - \cdot 043 = \cdot 270$ equivalent of china clay, which will include $\cdot 270 \times 2 = \cdot 540$ equivalent of silica. This, added to the silica taken with the felspar, will give $\cdot 258 + \cdot 540 = \cdot 798$ equivalent of silica out of the $1\cdot 333$ required, leaving $1\cdot 333 - \cdot 798 = \cdot 535$ equivalent to be added as flint. The bone is calculated in a similar manner. There is to be supplied $\cdot 243$ equivalent of phosphoric acid. Each equivalent of bone ash will contain one equivalent of phosphoric acid and three equivalents of lime, therefore $\cdot 243$ equivalent of bone will contain also $\cdot 243 \times 3 = \cdot 729$ of lime, leaving only $\cdot 857 - \cdot 729 = \cdot 128$ equivalent to be supplied, but as both china clay and felspar contain traces of lime, this small amount may fairly be disregarded. Multiplying now each equivalent by the proper combining weight the mixture is completed.

Felspar	.	.	$\cdot 043 \times 278\cdot 4 = 11\cdot 97$	parts.
Kaolin	.	.	$\cdot 270 \times 129 = 34\cdot 83$	„
Flint	.	.	$\cdot 535 \times 30 = 16\cdot 05$	„
Bone Ash	.	.	$\cdot 243 \times 171\cdot 5 = 41\cdot 67$	„

The same analysis could be worked out on the basis of Cornish stone instead of felspar, allowing

to each equivalent of stone one of alkali, two of alumina, and eighteen of silica. The composition of stone is, however, so variable that it is impossible to fix exact equivalents or an accurate combining weight.

A glaze analysis may be worked out upon the same lines, but here the modern method, introduced by the German ceramists, is to separate the glaze constituents into three divisions, bases, alumina and acids, and in order to institute an exact comparison and to adjust the balance of power, the bases are first added together and multiplied by some number, which will bring the total to 10 or 100, treating, of course, the other constituents in the same way.

An average analysis of a good lead glaze would be for example :—

Silica	.	.	.	50·00 ÷ 30	= 1·666
Alumina	.	.	.	12·00 ÷ 51	= ·235
Lime	.	.	.	1·25 ÷ 28	= ·044
Soda	.	.	.	5·25 ÷ 31	= ·169
Boracic Acid	.	.	.	6·50 ÷ 35	= ·185
Oxide of Lead	.	.	.	25·00 ÷ 111·5	= ·225

The boracic acid and the soda being, of course, in an anhydrous condition, the smaller combining weights are used.

Dividing now the bases and acids into groups, and placing the alumina in its intermediate position, the formula will stand thus :—

Lead Oxide PbO	·225	} Alumina Al ₂ O ₃	·235	{ Silica SiO ₂ 1·666. Boracic Acid B ₂ O ₃ ·185.
Lime CaO	·044			
Soda Na ₂ O	·169			
		<hr/>		
		·438		

Now, it will be seen that the bases only amount to ·438 equivalent all together, and, therefore, to bring this to unity, each figure must be multiplied by a particular number. This number in the present case is found to be 2·283, and the formula will then be resolved into the following :—

PbO	·5137	} Al ₂ O ₃	·5365	{ SiO ₂ 3·8034. B ₂ O ₃ ·4223.
CaO	·1005			
Na ₂ O	·3858			
		<hr/>		
		1·0		

The calculation will then proceed somewhat upon the lines laid down for bodies, but a new substance, boracic acid, has to be dealt with. This is most conveniently taken in the form of borax, each equivalent of which contains two equivalents of the acid and one equivalent of soda. Therefore, ·2111 equivalent of borax will contain all the boracic acid needed and ·2111 equivalent of soda, leaving ·3858 - ·2111 = ·1747 to be taken as soda ash. The alumina will be supplied as before by china clay, and the remaining silica by flint. The figures will now read :—

White Lead	·5137
Whiting	·1005
Borax	·2111
Soda Ash	·1747
China Clay	·5365
Flint	2·7304

But it becomes necessary to incorporate some of these substances in a fritt, and, as the borax, soda ash, whiting, and china clay, all have water or carbonic acid to lose, allowance must be made accordingly. Soda ash and whiting lose their carbonic acid in the fire, and, therefore, become subject to the combining weight of sodium oxide and calcium oxide respectively. For the fritt then there would be taken :—

Borax	·2111	equivalent	40·10	parts	melting to	21·32	parts.
Soda Ash	·1747	„	9·25	„	„	5·41	„
Whiting	·1005	„	5·02	„	„	2·81	„
China Clay	·1365	„	17·60	„	„	15·21	„
Flint	·7304	„	21·91	„	„	21·91	„
						<hr/> 66·66	

And to complete the glaze there would be ground together the charge of fritt, which, of course, should be re-weighed, and the balance of the materials, thus :—

Fritt	66·66	parts.
White Lead ·5137	equivalent	66·26 „
China Clay ·4	„	51·60 „
Flint 2·0	„	60·00 „

By these means any analysis can be reduced to a workable condition, and can be made of real assistance to the practical potter.

TABLE OF COMBINING WEIGHTS.

In order to assist those desiring to work out calculations for themselves, the following table of the combining weights of the substances in most general use has been compiled :—

Alumina Al_2O_3	51
Bone Ash $\text{CaCO}_3 \cdot 3\text{Ca}_3\text{PO}_4$	171.5
Boracic Acid B_2O_3	{ Hydrated . 62
	{ Anhydrous 35
Borax $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$	{ Hydrated . 190
	{ Anhydrous 101
Calcium Oxide CaO	28
„ Carbonate CaCO_3	50
„ Phosphate Ca_3PO_4	155
Ferric Oxide Fe_2O_3	80
Felspar $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$	278.4
Kaolin $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 + 2\text{H}_2\text{O}$	129
	{ Calcined 111.5
Petuntse or Pegmatite, very irregular	probably 680 to 690
Lead Oxide PbO	111.5
White Lead $\text{PbH}_2\text{O}_2 \cdot 2\text{PbCO}_3$	129
Magnesium Oxide MgO	20
Potassium Oxide K_2O	47
„ Carbonate K_2CO_3	69
Quartz (Flint) SiO_2	30
Sodium Oxide Na_2O	31
„ Carbonate Na_2CO_3	53

CHAPTER III.

POTTERS' CLAYS; AND THEIR COMPONENTS.

I.—THE COMPONENTS OF CLAYS.

THE necessary constituents of potters' clays are very limited in number.

Alumina, the chief, is in itself highly infusible; but when mixed with silica is more or less fusible, according to the proportion of each ingredient.

Silica or silicic acid is present in clay both in a free state in the form of sand or quartz, and also in combination with the alumina. The fusibility of the mass is greatly affected by the condition in which the silica occurs, and for this reason chemical analysis gives but little indication of the qualities of a clay, apart from empirical tests.

Water is present in all plastic clay, and the plasticity of a clay is in direct ratio to the amount of *combined* water contained in it.

In addition to the combined water there is usually some amount of water in a free state which

may be expelled by drying at a temperature below boiling-point. It is always desirable to eliminate this portion of the water from samples of clay before commencing an analysis.

In addition to the components already named, most clays contain some proportion of basic earths and alkalies. Of the former, lime and magnesia are the most important.

Lime is infusible when pure, but very fusible when combined with silica, alumina, or alkaline silicates. A very small percentage will greatly affect the character of a clay.

Magnesia occurs in small proportion in many clays. It is infusible when pure, and when combined with other materials tends to reduce the plasticity of the body. It is largely present in magnesite, an important ingredient in some Spanish porcelains.

The *Alkalies*—soda and potash—add greatly to the fusibility of a body when in combination with the other materials, readily vitrifying with silica, lime, or barytes.

Other ingredients and some metallic oxides occur at times in clays. Amongst these

Ferric Oxide is by far the most general. Its presence adds greatly to the fusible qualities of the clay, and it imparts a colour to the mass, buff, yellow, red, grey, or black, according to the

proportion present or the conditions under which it is fired.

THE TESTING OF CLAYS.

It is always needful to ascertain the *exact* nature of a clay to be used for potting purposes before adopting it. At first sight it might be supposed that in the case of clays intended for use in coarse wares only this would be an unimportant preliminary. But this is by no means the case, for the following reasons :—

The clays for *fine* wares undergo washing, sifting and intimate admixture in the slop state. But in the case of *coarse* pottery the clay must be used in its natural condition. The large expense of such preparation obviates the possibility either of removal of foreign and deleterious matter or of obtaining a perfect combination with other ingredients which might assist to correct any faulty qualities.

The knowledge of these qualities must therefore be accurate, and it is seldom worth while to make a test at all unless a definite conclusion can be deduced. If the conditions are not definitely known, and the comparative tests are not made under identical circumstances, the results can only be misleading. Many disastrous losses have accrued to manufacturers from want of accurate data on these points.

It is equally important that the tests should be exhaustive. It must be borne in mind that many clays are inconstant in their qualities, varying greatly according to the position in which they occur. A single sample is, therefore, no criterion of the bulk. A series of samples should in all cases be taken over a large area—definitely located and identified, or thoroughly mixed together before testing, if an average result be sought for.

It is hardly necessary to add that the tests should be systematic. Results are often important for reference in the future, and if not uniformly marked, in numerical rotation, with clearly distinctive method, hopeless confusion ensues. Arbitrary choice of letters or signs soon passes from the mind, and tabulation of data becomes unmanageable, if not impossible.

Passing on to deal with the nature of the tests, it will be observed that they are either physical and technical or chemical and analytical. That is to say, the potter may either examine the natural properties and the physical condition of the particles and of the mass by empirical methods; or may proceed to ascertain the components by a laboratory analysis, determining the accurate proportions of each.

Both these operations are really necessary for success, but it is certainly true that chemical

analysis alone is not sufficient to guide a potter in the selection of his clays.

It is, therefore, important that physical and technical tests should be efficiently carried out; and the following observations have for their object the assistance of the manufacturer in obtaining such results.

The conditions under which clay is worked and the purposes for which it is used are so various that it is difficult to lay down any general instructions which will apply to all classes of tests and all kinds of materials. In every case, however, it will be desirable to obtain information on the following points :—

1. Plasticity, or formative quality.
2. Tenacity, or binding properties.
3. Uniformity of texture and homogeneity.
4. Shrinkage at various temperatures.
5. Porosity after firing at these temperatures.
6. Vitreousness, or density after firing.
7. Colour when fired and glazed.
8. Glazing properties.

For the purposes of definite comparison it is very important that the methods adopted should be reducible to figures.

1. *Plasticity*.—The plasticity of a clay will be found to depend largely upon the condition and quantity of the silica contained in it. The coarser

the sand particles, and the greater their quantity, the less the plasticity. Obviously, however, those clays, which are coarse and open in body, are more absorptive, so that they readily take up water ; but with the addition of the same quantity of water a plastic clay is far more resistant to displacement than a non-plastic clay.

Making use of this fact, it is possible to obtain comparative tests of plasticity in two ways. By the first method, the sample of clay is first thoroughly dried and pounded, a measured quantity of water being added to a given weight of clay sufficient to render it plastic enough for ordinary work. Having thoroughly mixed the mass, a small portion of it is pressed tightly into a metal ring, the upper surface being struck off perfectly level with a spatula.

To gauge the plasticity for comparison with other samples it is now needful to ascertain the resistance of the mass to the penetration of a steel wire of a given size under a known pressure.

It is by no means difficult to devise a method of supporting the needle in such a way that the distance of its descent in a given time can be read off on a vertical index, and if the behaviour of a standard clay under these circumstances be first noted, the comparison of other samples similarly treated can be easily accomplished.

Such an apparatus has already been devised for cement testing, and is termed a "Vicat" needle.

A second, and simpler, though less accurate, method, is to take a sample of the dry ground clay moistened as before with a known proportion of water, and to form the mass into a cylinder by forcing it tightly into a metal tube. It is then carefully expelled from one end by means of a plunger exactly fitting the tube.

The cylinder may now be supported horizontally in a semicircular channel of the same diameter, and so arranged that a wire can be strained across it at right angles. By attaching a known weight to the end of the wire and recording the time occupied in severing the cylinder a comparison of the plasticity of the clay may be fairly accurately attained.

2. *Tenacity*.—The tenacity or binding property of a clay does not always follow its plasticity, nor is the tenacity greatest in the "white hard" state. In most cases, however, it will be sufficient for practical purposes to ascertain the tenacity in this condition.

It is possible approximately to estimate this by the following method. A strong rectangular metal frame 1" deep 1" wide and 3" long is obtained, and into this a piece of the clay to be tested, previously moistened to a plastic state and carefully mixed, is

inserted. This clay should first be cut as nearly as possible to the size of the frame, which must be previously oiled slightly inside. The frame being now placed on a flat slab of plaster is completely filled with the sample of clay, the superfluous portion being carefully struck off level with the top.

On removing the clay from the mould, great care must be taken to prevent distortion.

The moulded block is now thoroughly dried, and for the purpose of testing should be supported on two bars of metal $\frac{1}{2}'' \times \frac{1}{2}''$ in section, fixed horizontally and parallel to each other on a wooden stand at a distance of exactly 2" apart.

The amount of weight which when applied to the centre of the moulded block causes fracture, will furnish data of comparison as to tenacity. The result may be expressed in ounces per square inch of section. In this case also the apparatus employed for testing cement will be found suitable, and this, moreover, may be readily obtained without special manufacture.

The calculation must, of course, be made on the sectional area of the block when dry, otherwise the comparison may be affected by the variation in shrinkage of the different blocks.

3. *Uniformity of Texture.*—The importance of this quality is greatly increased in the case of such clays as are intended for coarser manufactures in

which it is impossible to afford the outlay in preparation necessary to render them homogeneous.

To obtain a knowledge of this, it will be most useful to take test-pieces of the clay from different portions of the bulk, and these being first thoroughly dried should, if possible, be shaped with a knife to a uniform rectangular size.

The condition of the surface, texture, and colour should be noted before and after firing, comparison being made of the amount of variation between the different pieces.

The occurrence of granules of quartz, iron oxide, lime, lignite and other vegetable matter will need careful attention, especially in those instances where the clay is intended to be used without washing.

4. *Shrinkage*.—To obtain accurate data as to shrinkage requires some care. The shrinkage of a clay is chiefly due to two causes, *viz.* :—

The evaporation of the water in the mass during the process of drying, and

The parting with the combined water, together with other chemical changes which take place during the firing.

It is most desirable to ascertain the amount of shrinkage due to each of these causes separately.

To ascertain the shrinkage in drying, a portion of the pounded clay is mixed with 29 per cent.

weight of water, and made up into a slab 7" long in a plaster mould. Upon the face of this a length of 6" is marked. The piece is then removed from the mould and allowed to dry steadily. The length marked on the clay will now be less than 6". A second 6" length is marked off as before, and the difference in length between the two is carefully noted. Multiplying this difference by 2 the amount of shrinkage per foot length is obtained.

By setting off the shrinkage marks in centimetres instead of inches the results may be more easily converted into percentage, if so desired.

The marked slab of clay must now be passed through the biscuit oven, and after firing a new 6" length is marked parallel to the others on the burnt ware. The differences are carefully noted and multiplied separately by 2, as before. The shrinkage from plastic to biscuit and from white hard to biscuit will now be indicated on the clay itself.

This method also affords an accurate comparison of the ratio of shrinkage in drying to that of shrinkage in firing.

It is necessary to bear in mind that the shrinkage of a clay does not always increase in the same ratio as the firing temperature. Test-pieces should therefore be fired in different positions and

in different kilns to ascertain the relative shrinkages at different heats.

5. *Porosity*.—The porosity after firing at a given temperature may be arrived at by noting the weight of water absorbed by a piece of burned clay when thoroughly saturated. The piece to be tested should be first accurately weighed and then placed in a shallow vessel of water for twenty-four hours. It is better to leave the upper surface exposed, to allow the air to escape, which, if the whole surface were immersed, might remain imprisoned in the pores.

The saturation will be more easily effected if the water is allowed to soak through a fractured end, as the surface of the fired clay is often less porous than the interior.

After soaking the piece is removed from the water and the surface wiped dry from superfluous moisture. The weight is again carefully taken and the increase observed. Multiplying this difference by 100 and dividing by the original weight, the quotient will be found to give the absorption per cent.

6. *Density*.—The density of a clay may be ascertained by its specific gravity, which is usually compared with that of water.

The burnt clay is first weighed accurately, and then weighed again while immersed in pure water

at 60° F, by hanging the piece from the scale on a fine horse-hair, taking care that all attached air-bubbles are removed. The piece will now weigh lighter than before, and by deducting the latter weight from the former and dividing the remainder into the weight of the piece in air, the quotient will give the specific gravity. Thus :—

Weight in air	-	-	-	200
Weight in water	-	-	-	120

$$200 \div 80 = 2.5 \text{ specific gravity.}$$

For all practical purposes it may be assumed that the specific gravity will give sufficient indication of the relative vitreousness of different samples of clay.

7. *Colour after firing.*

The colour of clay is affected.

By presence of metallic oxides.

By the presence of earthy substances, chiefly lime.

By the conditions of the firing process.

Oxide of iron is the most frequent colorant of clays, but is so greatly influenced in its action by the quality of the fire (whether oxidising or reducing), as well as by the temperature attained, that it is important to verify results by a series of tests in different parts of the oven, and, if possible, in different ovens.

Minute variations in colour can be better appreciated when the biscuit ware is glazed with a thin transparent glaze of known composition. Impurities in the body are also more easily detected by this means.

The presence of other earths will also affect the colour of the fired clay. Thus barytes will whiten, while lime will, in the presence of iron, tend to impart a yellowish buff tint.

8. *Glazing properties (and co-efficient of expansion).*

The clay may in all other respects be suitable, but when fired under glaze the latter may craze, or it may splinter, or it may shatter the ware itself. It is therefore necessary to test its glazing properties by dipping in a glaze of known composition and noting the result after firing.

It is, however, very undesirable to form conclusions on this point too precipitately. Additional thickness of glaze will often cause test-pieces to show crazing when the manufactured ware might prove sound.

On the other hand a test-piece may come from the oven sound, and the crazing or other defect may only appear after a long period of time. Great caution should therefore be used in arriving at conclusions on this point.

Many other facts in connection with clays and

their qualities might doubtless prove interesting to examine, and some are important in special manufactures, but the tests indicated will be found to suffice for all general purposes of pottery manufacture.

CHAPTER IV.

THE BISCUIT OVEN.

I. *The Oven*.—The best known form of pottery oven in England is the up-draught, built with dome and hovel. The fire is applied in eight or more mouths, which enter the firing chamber through the “bags” built up inside. There is no doubt that this type of oven is wasteful of heat and difficult to control, but so strong are the prejudices of firemen, and so great is the dislike of the manufacturer to experiment with matters relating to firing, that the up-draught oven holds the field.

The down-draught oven is more correct in theory, as the products of combustion pass through the firing chamber twice instead of once, but this oven needs a far stronger current of air. In other words, a chimney-stack is necessary to secure good results. The longer distance traversed by the flame renders a strong draught indispensable. Fuel is economised, but, on the other hand, it is difficult to get sufficient heat on the bottom of the oven. For this reason ovens of the latter

type are built somewhat low in the crown, so as to provide for a more thorough diffusion and deflection of the heat through the mass of ware.

There are other methods of constructing ovens which are but little known in this country. The ancient Chinese built their ovens one above another upon a hill side, and, beginning at the bottom, they carried the waste heat through the upper kilns. Some principle of the kind has been adopted at Limoges in the two-storied ovens, but the most complete method is the arrangement of six or more ovens in a circle, each communicating with an annular flue and, through this, with a central chimney-stack. By an arrangement of dampers the waste heat can be conducted from any one oven to its neighbour on either side, thus heating the newly-placed oven to redness before an ounce of coal is used. So far as we are aware this method has not been successfully employed in England, but the theory seems sound, and ought to be tried.

After all, it is hardly to be expected that such advice as can be given in a work of this kind will induce any manufacturer to build new ovens; and the most useful course to adopt will be to point out what may be done to economise with the existing plant and to save loss in firing.

2. *Placing*.—Good placing is the foundation of

good ware. The bed influences the shape of the piece in a very large degree. With hollow ware the placer has not very much to do. He must see that covers where fired with the bottoms or middles are set on true, with a little flint on the verge, and that over-hanging parts are bedded up well. This applies both to China and earthenware, though more especially to the former. In cases where the piece may be expected to sustain its own weight it is better without a bed. The unequal resistance of flint or sand often causes crookedness where the unbedded piece might have kept its shape. Lengthy pieces, such as tubes, are often better hung than laid flat; but this can only be accomplished when there is on the piece a flange or collar to support the weight.

Vases and similar ornamental pieces will generally, if properly made, stand firing with but little support, but it sometimes happens that a more than usually elaborate handle, or, perhaps, a lightly modelled figure, will need special assistance. Much, of course, depends upon the body in which such pieces are made, but it will be found useful to cast a thick "chum" or cylinder to surround the delicate piece and to prop the parts from the sides and top of this. The props and chum are, of course, made from the same clay as

the piece to be supported, and for this purpose scraps, too dirty for best use, may be worked up.

In pressed ware, which includes thrown and turned and also jollied work, cups and basins sometimes cause loss by reason of defective shape. A non-circular cup is an abomination, and the ring is not always satisfactory. The angle at which the ring is turned is a matter that is too often left entirely to the discretion of the turner. As a matter of fact, hardly two shapes of cup need a ring of the same angle. The angle will vary from 120 to 170 degrees as extremes, and every manufacturer should know the exact angle required by each cup he makes. It is a simple matter to construct a gauge for the use of the turner. A strip of thin steel is cut to the angle required, and this gauge being applied now and then ensures the correct angle being kept. Cast cups require a wider angle than turned cups, but it sometimes happens that a very wide angle does not exert sufficient power over the cup to keep it circular. In that case either the ring should be made heavier, or the cup should be inverted upon the ring and a small piece of sagger placed on the foot as a weight. This increases the pull of the ring and enables it to perform its function. Flat ware as a general rule burns best on a "face" bedder, or if a bedder be not necessary the ware is placed

face downwards. There are some exceptions to this, and obviously ware with embossed patterns cannot well be placed in this way. China plates have a tendency to rise at the edge when turned face downward, and to prevent this a slight weight either of a light ring or a ridge of flint is advisable. It will be found that there is in the section of any piece of flat ware a certain line of equilibrium. Pieces, the section of which is deeper than this, will deepen yet more, while those that are flatter will become still more flat. This must be taken into account when making bedders for plates and saucers. Considerable art is here necessary on the one hand to form a bed tight enough to keep the piece straight, and on the other to allow sufficient liberty for contraction and deepening.

Earthenware, on account of its comparatively slight contraction and small amount of vitrification is but little dependent upon the bed. Plates are usually placed together a number in a sagger, each forming its own bed on the top of another. Sand is used in this work in preference to flint. First because the greater porosity of the sand allows a free movement of the ware in contraction, and secondly because in drawing the kiln flint would make an excessive dust. China plates being removed one by one from the setters the flint is not

disturbed, but upon emptying a sagger full of earthenware plates the whole of the bedding is shaken out. The dust raised by sand is bad enough. It would be unbearable if flint were used.

The sand or flint used in making beds is slightly damped to cause adhesion. This requires to be carefully and evenly done, for were the bed too damp in any one place the result would be a stain upon the fired ware. Damp, wrongly applied, has a very prejudicial effect upon clay, and the evil is often not discernible until after firing. Ware left too long placed before firing sometimes experiences this. The damp of the bed will penetrate the clay and cause damage, or it may happen that the bed, through standing too long, has lost its solidity, in which case the slightest shake will disintegrate the flint and, as a result, put the ware out of shape.

Bedders are usually made of plaster, but on account of the rapid wearing action of the flint attempts have been made to construct them of clay and to fire them. The objections to these "pitcher" bedders are the extreme difficulty of getting them exact to size and their liability to chip. It is possible to coat or to harden plaster bedders so as to make them more durable. The white of an egg mixed with a little solution of potassium bichro-

mate will form a varnish which hardens under the effect of light, or the bedder may be saturated with weak gum-water to which a little bichromate has been added. Either of these methods will materially lengthen the life of a bedder.

The durability of saggors and setters has a very serious bearing upon the cost of firing. Five times firing should be the average of a sagger's existence, but it is very doubtful whether this is always the case. It is important that, as far as possible, a sagger should receive a harder fire in the first place than that which it will have to undergo in use. This is not always practicable, especially when the green saggors are, for the sake of economy, used to contain ware. Then, to make durable saggors, the clay should be aged and properly tempered. A sufficiency of "grog" will help.

It is hardly possible to use too much so long as the clay is workable, but the grog must not be too fine. To obtain clay that has been long exposed is not easy, and to accumulate large stocks for the purpose of weathering involves the sinking of capital, so that manufacturers are generally driven to take a middle course. Only, be it remembered that the older the clay the more economical will be the saggors. Placers are apt to find fault if the setters and saggors are made at all heavy, but it should be borne in mind that a strong

sagger as a rule lasts longer than a very light one, and it is better to tax the muscles of the kilnmen than the purse of the proprietor.

3. *Firing*.—Around the question of the fire hang most of the anxieties of the potter. He must consign his ware to the flames, where it is not possible for him to follow it, and where it must take care of itself without the chance of outside help.

It is to be regretted that in this matter of firing there is so little interchange of ideas amongst manufacturers. The keen nature of modern competition prevents one seeking the advice of another or the publication of the results at which any investigator may have arrived. Yet there can be no doubt that a comparison of methods would be of the greatest mutual advantage, and the potting industry would reap benefit all along the line.

Staffordshire is well placed as regards her coal supply. Some of the cleanest burning fuel of England is found beneath her soil, and the potters have taken full advantage of these stores. But to possess good coal is one thing, and to understand the use of it is another. It is feared that the average fireman knows very little about the scientific use of his fuel, and his ignorance leads to considerable loss.

In starting the fires care should be taken not to fill up the mouths too rapidly. At the beginning

a clear fire should be aimed at, which shall discharge hot air and not smoke into the kiln. Gradually, as the mouth and bag become heated, the fuel may be cast on more liberally until, as the walls begin to glow, the fire-mouth becomes a generator, from which the gas passes into the firing chamber before its combustion is completed. A biscuit oven can receive a vast amount of fire with apparently no result. Every sagger and every piece enclosed therein must throughout its entire substance be permeated by the heat, and this is a matter which must perforce take some considerable time. A gradual combustion is indispensable, and to effect this large coal is best. The mouths should be kept well filled, both to exclude an excess of air and also to prevent a too greedy attack upon the fresh baitings. If the mouth be allowed to burn half empty a strong oxydising flame enters the kiln, and when new fuel is supplied the keen rush of air and the rapid combustion carry a new flame charged with smoke and coal dust amongst the heated saggars. The result is flashed and discoloured ware and damaged saggars. All this is escaped if the mouths are fed a little before they seem to need it.

It is to be regretted that the ovens in use in England permit so little control of draught on the part of the fireman. He can open or close the air

holes on the mouths, but there his power seems to end, and, for example, in dull weather, he has no means of accelerating his draught. It would be a decided advantage if the ovens could be connected with a chimney-stack to get the maximum draught, and that this should be brought under control by means of dampers. The admission of air could then be regulated by the fireman, and greater uniformity would be the result.

During firing the interior of the oven is in a state of low pressure. In consequence of this there is an inward rush of air, under the greater pressure of the atmosphere, through every crack and cranny. To ascertain the amount of this outside pressure an ingenious kiln-barometer has been devised. Its construction is very simple. A tube is inserted through the wall of the kiln, and the brickwork around it is made air-tight. The outer end of the tube leads to a box, upon which a graduated glass gauge is fitted. The low pressure in the oven exerts a suction upon a liquid contained in the box, and thus readings of the amount of pressure can be taken. It is not necessary here to give details of construction, for the principle being made known, any ingenious superintendent should be able to have an instrument carried out to his liking.

Such a barometer would at once indicate any

excess or deficiency of draught, and by this it would be possible to judge whether the burning fuel were employing too much or too little oxygen.

4. *Loss in the Biscuit Oven.*—The losses in the biscuit oven may be broadly divided under two heads: those caused by the maker and those caused by the kiln. With the former this is not the place to deal, but it may be stated that the makers' losses include bad throwing, turning and casting, cracked handles, bad seams, and untempered clay. The kiln losses may be sub-divided into losses of the placer and losses of the fire. The placer is mainly responsible for bad shape, crooked plates, saucers and cups, and for the falling of pieces which should have been supported by the bed. To his account must also be laid ware nipped and strained in the clay, a class of fault to which flat ware is especially liable. The losses of the fire are numerous and severe, probably 80 per cent. of biscuit kiln loss is caused by the fire alone. The most prolific source is fire cracking. Apart from the "straining" already mentioned there is a vast amount of "fire-crack" pure and simple, which no amount of vigilance seems to diminish. The inability of superintendents to check this loss is partly due to an erroneous belief as to when this cracking occurs. It is generally understood that the contraction of the ware is the cause

This is not entirely the case. A short-fired oven has invariable less fire-cracking than one which is fired up, and yet even in the shortest fired oven all the contraction has taken place. The fact is the crack is the result of extreme tension at the time of greatest vitrification. This tension is the result partly of the bed and partly of the molecular arrangement of the clay under fire. It can to some extent be modified by a due consideration of the tendency of all ware to rebound from the line of equilibrium already spoken of, and also by careful accuracy in firing off. The fireman can save a good deal of the fire-cracking by watchfulness, for the least amount of over-fire invariably means greater loss. This applies, of course, in the main to china. Earthenware is not subject to fire cracks to anything like the same extent.

There is no doubt that a good deal of oven loss may be avoided by a careful examination of the green ware. In the clay small cracks are often discernible, which would, of course, be developed by the fire into fatal defects. There is, however, great risk in handling green ware, and without a very delicate touch the remedy becomes worse than the disease. In plates the foot-crack can often be checked by diminishing the number piled up in one bung when green. It is mainly the bottom plate that suffers, both from the weight

of its companions and from the irregular surface of the board.

The loss in a china biscuit oven should not exceed 8 per cent. In addition to this there will be a proportion of seconds and thirds, according to the standard of the manufactory, but the absolute loss may be kept well within this figure. It is simply a matter of vigilant and patient care.

CHAPTER V.

PYROMETRY.

THE science of pyrometry concerns itself, as the name implies, with the measurement of heat, and has always been understood to refer to the recording of temperatures beyond the reach of the thermometer.

Since the days of Josiah Wedgwood but little advance has been made by English potters in this study. They are for the most part content to go on using the rude tests of their forefathers, and it is very difficult to excite any enthusiasm for a new system.

Wedgwood's pyrometer consisted of a brass tablet about six inches long, in which was a tapering groove running the whole length. This groove was graduated to degrees, and the instrument was worked upon the principle of the contraction of clays. A number of small slabs of clay were prepared and placed in the oven, when the firing was in progress one of these was withdrawn, and when

cold was passed into the brass groove, the distance it would travel towards the narrow end indicated the amount of contraction that had taken place, and by deduction, the amount of fire which the kiln had undergone.

To this method there are two great objections. First, the extreme difficulty of obtaining continual supplies of clay absolutely uniform in shrinkage ; and second, the fact that contraction does not correctly indicate the amount of firing or the degree of heat. For example, in the china biscuit oven, all the contraction will have left the body long before the point of translucence is reached, and further, in most, if not in all wares, after the shrinkage has taken place a reaction will set in under continued fire, resulting in a slight expansion, which would entirely upset any calculation based upon delicate measurements. If anything is to be learned from the contraction of clay in the fire, information must be gathered not only as to the amount of that contraction, but also as to the time at which it takes place, and the period over which it extends. If in a fire-clay tube, with closed end, a cylinder, about seven inches long, of unburned clay be placed, and upon the end of this the pressure of a spring brought to bear, the length of the clay cylinder will give an appreciable amount of movement during contraction, and this

motion may be made, by suitable mechanism, to register its path, as a diagram, upon a graduated scale, much in the same manner as the chart of a recording barometer is produced, and while this does not afford a satisfactory guide to the fireman, it gives valuable data as to the progress of events inside the oven. It is found, for example, that, in a china biscuit oven which is under fire for thirty-eight hours, the first twenty hours are occupied in gathering heat. Then the contraction begins, and continues for some seven hours, while the remainder of the time is needed to secure complete vitrification. The diagram thus recorded also shows whether the shrinkage has been uniform or not, and recent investigations go to show that a regular contraction carries with it a smaller amount of loss than an intermittent, notwithstanding that the former may be far more rapid than the latter. The shrinkage of earthenware has been known to run its entire course in less than three hours without damage, while in another firing a contraction, occupying twice the length of time, but with less regularity, was not so satisfactory.

Many persons have a difficulty in separating the question of firing from numerically expressed degrees of temperature. At great heats the actual number of degrees reached is more or less a matter of conjecture, and after all it is of no importance.

What is wanted is to get the ware right, and having once secured a good oven to be able to do so again.

Undoubtedly the most satisfactory method of gauging ceramic fires is that introduced by Professors Seger and Cramer at Charlottenburg, and known as the "Normal Pyrometric Cones".* The principle is that certain mixtures of clays and alkalies fuse at different points, according to their composition. These mixtures are made into pyramids or cones, six centimetres high and one and a half centimetres on each side of the triangular base. One of them is placed in the oven where it can be seen from outside, and when the point of the pyramid bends so far as to touch the base level, the required temperature is reached. This system has rapidly gained ground upon the Continent and in America, and it is certain that its adoption here would lead to far more regularity in firing, and would moreover enable the manufacturer to more effectually check the operations of his firemen.

The chief difficulty in the use of these cones lies in the fact that the cone mixture must be adapted to the existing temperature of the oven. A heat is already in use, in every manufactory, which is suitable to the ware, and it becomes

* The editor is indebted for much information regarding these cones to a valuable work on *The Chemistry of Pottery* by Karl Langenbeck. Pittsburg, Pa., The Chemical Publishing Co.

necessary to compose a cone for each set of ovens, which will exactly bend to its lowest point when that oven is sufficiently fired. Moreover, in firing an oven repeatedly week after week, it is not possible under the present system to secure absolute uniformity, and therefore a cone which appears satisfactory one week will seem too soft or too hard the next. Patience is necessary to subject a selected mixture to a long average of trials, so that the exact melting point may be assured.

The normal cones range over a wide series, fusing from estimated 1760° F. (960° C.) to over 3000° F., but this great variety is, of course, not necessary for an English manufacturer. It may be taken that felspar melts almost to a clear glass at china biscuit heat, and this melting point of felspar is estimated to be 1400° C.* On the other hand, an earthenware printed oven at its lowest point is more than sufficient to fuse silver, the melting point of which metal is estimated to be 960° C. It will, therefore, be safe to say that in England glaze kilns range from 1000° C. to 1300° C., earthenware biscuit ovens from

* As Centigrade or, what is the same thing, Celsius, temperatures are given in almost all scientific works, it may be more convenient to adopt the same scale here, giving the following formulæ for the conversion of Fahrenheit into Centigrade and *vice versa*.

$$F. = \frac{9}{5} C. + 32. \quad C. = \frac{5}{9} (F. - 32).$$

1200° C. to 1350° C., and china biscuit ovens from 1300° C. to 1450° C. But these figures are points of only academic interest, they do not greatly help the practical potter. What is wanted is a mixture to fuse at each required heat.

For the softer cones a fritt must be made of, say :—

Borax	-	-	-	-	190	parts.
Whiting	-	-	-	-	50	„
China clay	-	-	-	-	50	„
Flint	-	-	-	-	95	„

And for a composition bending at the heat of printed glost there would be taken, say :—

Of the above fritt	-	-	-	-	33	parts.
Whiting	-	-	-	-	30	„
Felspar	-	-	-	-	50	„
China clay	-	-	-	-	10	„
Flint	-	-	-	-	60	„
Ferric oxide	-	-	-	-	15	„

For a cone to bend at earthenware biscuit heat the mixture would be something like this, the fritt being unnecessary :—

Felspar	-	-	-	-	85	parts.
Whiting	-	-	-	-	35	„
China clay	-	-	-	-	30	„
Flint	-	-	-	-	80	„

And for a cone to suit the china biscuit oven there should be taken :—

Felspar	-	-	-	-	85	parts.
Whiting	-	-	-	-	35	„
China clay	-	-	-	-	80	„
Flint	-	-	-	-	200	„

It will, of course, be understood that these mixtures are only suggestions, but they are based upon the actual compositions used by Professor Seger. It will be necessary for each manufacturer to modify them according to the heat at which he is firing, and this modification can usually be effected by simply diminishing or increasing the amount of flint.

For the manufacture of the cones themselves it will be necessary to model a cone in stiff clay, and to have it moulded in the ordinary manner, if laid face downwards a "single" mould can be run, which will answer every purpose. It will be well, however, to have half a dozen of these moulds before beginning to make the cones.

The proper mixture must be well ground on a small pan, and when dry a portion is taken and mixed with about one-tenth of its *bulk* of dextrine powder. Water is now added, and the mass worked up into a stiff clay. This can then without difficulty be pressed into each of the moulds and taken off level with a knife or wire. For convenience of reference each different make of cone should have a number impressed upon it before it leaves the mould. If some old type is at hand these numbers can be made sufficiently bold and deep to be easily read after firing. It will, perhaps, be found that the dextrine is apt to clog the

mould and to cause adherence. This may be partially relieved by dusting the mould with some of the dry mixture; but, in any case, it is desirable to gently detach the cones from the moulds by means of a fine tool, otherwise the drying of the clay will cause breakage at the finer end. The use of the dextrine is to harden the cones so that when dry they may be handled with ease.

In the use of these cones it will be found necessary to bed them in a little soft fire-clay to prevent a possible fall, which would, of course, render the test entirely useless. Some difficulty may be experienced at first in seeing the cones when in the oven, but a little contrivance will obviate this. It is desirable to bring the cone as near to the front of the proof sagger as possible, and, of course, a cone must be set at each proof-hole if the kiln is to be fired by their means. In all probability it will be necessary for some time to use the usual tests in addition to the cones. A fireman can no more change his skin than can a leopard his spots, and it is not to be expected that an important and far-reaching alteration is to be made at once.

CHAPTER VI.

GLAZES AND THEIR COMPOSITION.

POTTERY glazes are of two descriptions, raw and fritted. The raw glaze is the simpler, and sometimes consists merely of a wash of lead or of pulverized galena sprinkled upon the moist clay. Such a practice is, however, most undesirable, and can hardly form part of the procedure of a reputable manufacturer.

A glaze may be used in its raw or unfritted condition when it contains no soluble salts such as borax or carbonate of potash, or when the alkaline earths such as lime and barytes are only present in small quantities. Under other conditions a fritt or glass must first be prepared. The soluble salts must be rendered insoluble by combination with other materials, and the earths must be more perfectly fused than could possibly be done in the ordinary heat of the glost oven.

It must be borne in mind here that the use of a fritted or a raw glaze is also governed by the con-

siderations under which it is to be worked and the nature of the body upon which it is to be used. Some wares require to be burned and glazed at one and the same fire, and it will be found easier to adjust a fritted glaze to a biscuit body and a raw glaze to a clay body ; neither does it follow that without alteration of mixtures the conditions can be successfully reversed.

In most cases fritting is accomplished in a specially designed furnace, where upon a sloping bottom of fire-brick the materials are melted together, to be run out when ready into a tank of water. Some fritts are, however, so hard that they refuse to flow, and some, especially if containing lead, exert too great an erosive action upon the kiln. In such cases the mixture must be put into saggers or crucibles, and either placed in one of the ovens or in a special kiln.

1. *Materials*.—The ingredients from which glazes can be composed are comprised in the following list, arranged approximately in order of fusibility :—

Kaolin.	White lead.
Quartz or sand.	Red lead.
Cornish stone.	Carbonate of soda.
Felspar.	Carbonate of potash.
Fluor spar.	Nitre.
Carbonate of lime.	Common salt.
Carbonate of barytes.	Borax.
Oxide of bismuth.	Boracic acid.

In addition to these there are various substances used for the coloration of glazes, which may be grouped respectively as earthy colorants, simple metallic oxides, or compound salts.

Kaolin or china clay supplies the largest part of the alumina in glazes, and is also useful for thickening the mixture in dipping, thus preventing the heavier particles from settling out.

Quartz, sand, or flint affords the usual source of free silica. For the preparation of fritts, white sand is in many respects the most suitable, as it requires no preliminary treatment. Flint and quartz need to be calcined and ground before use, and although the composition of these varies but slightly, their qualities differ sufficiently to make it important to avoid substitution when possible. Flints are prepared by either wet or dry grinding, and those picked from the beach on some parts of the Sussex coast are by many considered the best.

Cornish stone is believed to be produced from decomposed granite and is valuable in a glaze, partly as a source of alumina and partly on account of the silicate of potash it contains. As the composition of the stone varies considerably, it is important that tests should be made, as described upon another page.

Felspar is found pure in many parts, sometimes in large masses. It is liable to contain small

quantities of lime, soda, and occasionally magnesia. Felspar enters largely into the composition of glazes used for porcelain and stoneware, as well as those for glazed bricks. At the ordinary heat of the porcelain fire it melts into a semi-opaque glassy mass, and it is often usual to trust solely to this fusibility as a test of quality. This is, however, not entirely satisfactory, as the proportions of lime and alkali are somewhat variable. It is, therefore, desirable to make, if possible, an analysis. In the chapter on analysis the composition of a variety of spars from different sources is given.

Fluor spar is much more fusible than felspar and is greatly used in some parts of Germany. Quite insoluble in water, it occurs in crystalline form and of various colours, often amongst veins of lead.

Carbonate of lime is usually introduced in the form of whiting, but a finer quality is sold as "Paris white". It combines readily with borax and lead to form fritts, which melt at a low temperature, but it is only with difficulty fusible with flint. Whiting is much used in the composition of felspathic glazes for stoneware and bricks.

Carbonate of barytes is sometimes used in glazes in which it is desired to avoid lead. Some colours are benefited by its influence, but it is not a completely satisfactory substitute.

Oxide of bismuth is fusible at a high temperature and, with silica, acts as a powerful flux.

White lead and red lead are important fluxes and indispensable to the English glazemaker. They are readily fusible and quite insoluble in water. Both materials can easily be obtained of sufficient purity, but commercial white lead at all times contains some proportion of hydrate, besides being liable to adulteration with sulphate of barytes. The deleterious properties of lead render it advisable to fritt many glazes which might otherwise be used raw, it having been clearly demonstrated that glazes in which the lead has been fritted are not injurious to the health of the workers.

Carbonate of soda is a most important ingredient in glaze making, although in a humid atmosphere it is liable, if used in excess, to effloresce from the glaze. In proper combination with lead, flint, or barytes it will produce satisfactory results, and the alkalinity which it imparts to the glaze is necessary for the production of some colours.

Soda tends to render glazes pure and transparent, and is most conveniently used in the form of soda ash, though this is sometimes found to be adulterated with sulphate of soda.

Carbonate of potash is best used in the form of

pearl ash, but both the nitrate and the bicarbonate are available. Mixed with soda it produces fritts which are more fusible than those obtained from either salt when used alone.

Pearl ash is liable to vary in its composition, and should, therefore, be carefully analysed. It also attracts moisture rapidly, and the amount of this should be determined before use.

Nitre is used when greater purity is required, instead of pearl ash, for the introduction of potash into the glaze. Being rich in oxygen, it exerts a powerful influence in the elimination of any organic substances in the glaze mixture. It also adds to the brilliancy of the colour of some enamels. Nitre is a natural efflorescence from the soil in some countries; it is also produced artificially in France from refuse, and in other places from ammonia. Most of the supply now used in this country comes from the East Indies.

Common salt is often used in the production of stanniferous enamels. It is an extremely powerful flux and hence the presence of the smallest quantity is liable to considerably alter results. Salt is used for producing the glaze on salt-glazed stoneware, as well as in the composition of some smears and flows.

Borax is of the greatest importance in glaze composition. It owes its value largely to the

presence of boracic acid, of which it is the chief source, though the simple acid is sometimes employed. Its use in glazes makes them harder in surface and more brilliant. In large proportion it exerts a solvent action upon under-glaze colours. Borax alters the coefficient of expansion of a glaze in the same direction as silica, but affords a result which fuses at a lower temperature. It is occasionally rendered impure by the presence of the sulphates of soda and ammonia.

Borax is imported in its crude state from the East Indies under the name of tincal, while boracic acid comes from Tuscany, or is manufactured from crude salts found in Peru.

Occupying an intermediate position between the foregoing substances, which form the glaze itself, and the colouring earths and oxides, stand the white oxides of tin and zinc.

Oxide of tin is most valuable in the production of opaque glazes and enamels. Its chief property lies in the fact that it does not dissolve in the glaze, but is dispersed throughout the mass in white particles, which remain in suspension, thus forming a milk-white covering, as in Italian majolica.

Oxide of zinc is also white, but less opaque than the oxide of tin. It is an indispensable material for toning the shades of various colours. In this

capacity it is used in the production of yellows, greens, blues, and browns.

Of the earthy colorants, the most important are red and yellow ochre, umber and sienna. Ochres are largely used in producing the brown dip on the upper portion of salt-glazed vessels, and, indeed, for all purposes where a cheap form of iron oxide is required. All these substances are liable to such considerable variation in the proportion of iron present that they need to be constantly tested and analysed to maintain uniformity.

Umber contains about a fifteenth part of manganoous oxide and about one-third of oxide of iron. Its use in glazes is hardly desirable, as it usually contains a proportion of sulphate of lime which would prove detrimental.

The simple metallic oxides in use for colouring glazes are those of manganese, copper, cobalt, iron, chromium, nickel, and antimony; while the compound salts embrace the chromates of iron, barium, and lead. The effects of these colorants under different conditions will be dealt with in the chapter upon colour making.

2. *The construction of glazes.*—It is not difficult for the potter, after a long course of practice, to compose glazes from materials with the nature of which he has become familiar, provided that the glazes are to be used under known and tried con-

ditions. When, however, a glazemaker finds himself compelled to employ new substances in his glazes, to adapt them to entirely new bodies or to fire them under novel conditions, scientific knowledge will alone enable him accurately and promptly to avail himself of the teaching of his experience.

He may, it is true, patiently build up a new fund of empirical experience, but, meanwhile, much valuable time is lost.

It is for this reason that some knowledge of the principles underlying glaze composition becomes necessary as an adjunct to the usual practical experience with which, hitherto, so many glazemakers have been willing to remain satisfied.

Glazes are the result of the chemical combination of certain components under the influence of intense heat. The fusing together of these materials is the result of reaction between the silicic or boracic acids and the alkalies, alkaline earths or lead oxides, which act the part of bases, as in other chemical combinations. In addition to the bases and acids, it has been found necessary to introduce certain components which occupy a neutral position, but which, nevertheless, exercise an important influence upon the glaze. Foremost amongst these stands alumina, without which it seems impossible to construct a satisfactory

glaze, and it has been found that ferric oxide exerts a similar power. The office of these substances is that they prevent injury to the glaze by prolonged and repeated firing, and greatly assist the perfect adjustment of glaze to body.

If the component parts of a glaze are grouped in these three divisions—base, neutral, and acid—it becomes possible to construct a formula which is capable of comparison and adjustment without difficulty.

Glazes are subject to two great evils which overshadow many minor ones. These evils are “crazing” and “moulting”. The former is caused when the glaze on cooling contracts more than the body. The latter when the body contracts more than the glaze. This degree of expansion or contraction has nothing to do with the usual shrinkage of the clay in firing, but is the ordinary expansion under heat, followed, of course, by an equal contraction on cooling, which is a property of every substance. The constituent parts of the body and glaze and the fire undergone in biscuit and glost affect the degree of this expansion, and therefore it becomes necessary not only to assign a certain glaze to a certain body, but also to prescribe the degree of heat at which each shall be fired.

It is well known that a short-fired body will

cause the glaze to craze, but, on the other hand, an over-fired biscuit will also cause crazing, the reason of which is probably the slight permanent enlargement or swelling which takes place in over-fired wares. This seems to have the effect of diminishing the degree of expansion of the body, and crazing is the natural result.

Short-fired glaze will also be liable to craze, because the glaze is not complete until it has united itself with the body. At a full fire it does so, absorbing a portion of silica and alumina from the surface of the ware. When the fire fails to reach the point at which this can be accomplished, the union between body and glaze is incomplete and the modicum of clay is not taken up. This union must always be allowed for in composing the mixtures, for the more perfect it becomes in the fire the better will be the manufactured article.

It follows, therefore, that if a small amount of silica, preferably in the form of flint, be added to a glaze, it will serve as an antidote to crazing, but always with the effect of making the glaze harder. Boracic acid, as has already been remarked, exerts a similar influence, but increases the fusibility of the mixture.

Moulting is the opposite to crazing, but is not nearly so prevalent. The fact that this disease

almost always appears immediately after the fire renders it more easy to conquer. The usual cause of moulting is an excess of silica, either in the body or the glaze or both, and the cure is obvious.

A good glaze for under-glaze colours is sought after by every manufacturer, and in composing such it must be borne in mind that boracic acid on the one hand, and lead on the other, exert a solvent influence. These materials may be used in moderation, but the colours always suffer to some slight extent. Carbonate of barytes is sometimes helpful, but its use is often productive of other evils. Carbonate of calcium may also be employed without disadvantage, except that the fire needed for its fusion is fatal to some tints. The point to be aimed at in making a glaze for colours is to get the maximum of hardness with the minimum of fire. The heat should be only that which will give the glaze a bright surface. The glaze should be such as will melt without moving.

3. *Glost firing*.—Glost-oven losses are most aggravating to the potter, and are by no means easy to prevent. The faults most liable to occur in glost firing are enumerated below, and the endeavour will be made, if not to suggest a remedy, at least to point out the cause of each.

Crazing and moulting have already been

touched upon as belonging to the glaze itself. Pinholes are very troublesome in some glazes, but this fault belongs more especially to the body. An over-fired biscuit, too vitreous a ware, too finely ground body materials, or too hard a glaze, each will cause pinholes, and in each case there is, of course, an obvious remedy, but the cure of pinholes after glazing is a most difficult matter. They may be rubbed down and stopped, but the remedy is almost worse than the disease. Prevention is better than cure, and there is little doubt that this evil will invariably be found to arise from one of the causes above mentioned.

The so-called "sulphuring" is an oven fault pure and simple. It commonly takes two forms. Either the glaze is dulled on the surface and darkened in colour as if by smoke or it appears to be covered with a minute crystalline diaper. In the first case it is probable that the cause is the presence of a reducing atmosphere in the oven, or, in other words, there has not been enough air admitted to the mouths. A reducing atmosphere is that which is charged with carbon rather than with oxygen. This carbon has the effect of withdrawing the combined oxygen from the surface of the melted glaze and so disturbing the relations in which the constituent parts of the glaze ought to stand to each other.

Sulphur has, in fact, nothing to do with the case, except that a considerable amount of sulphur in the coal may cause excessive clinker, and thus check the draught. The remedy is a clear passage for the air and good luting, but the cure of defective pieces has so far been found impracticable. A certain amount of smoke is inseparable from coal firing, but a careful fireman will see that no baiting is put on too near the time of firing off. While the glaze is in a molten state a clear finishing fire will help to restore the bright surface, but if the ware be allowed to cool in a carbonaceous atmosphere the result will be disastrous.

The second evil which commonly goes by the name of sulphur, appears to be actually due to the presence of sulphur in the coal. It is not nearly so prevalent as the first-named trouble, but is caused, in the opinion of some who have investigated the matter, by a directly opposite influence. Too much air seems to have the effect of allowing any sulphur vapour that the combustion may liberate to attach itself to the glaze, and from this conclusion it would seem that a middle course, in the matter of the regulation of draught, will give the most satisfactory result, and that the periodical evolution of reducing gas as each baiting is performed is not without a useful effect upon the contents of the oven.

CHAPTER VII.

COLOURS AND COLOUR MAKING.

THERE is no more fascinating branch of ceramic chemistry than that which concerns itself with colouring agents and their behaviour under the varying conditions of the manufactory.

There are, doubtless, some to whom this is a field almost unexplored. If so, it is greatly hoped that the perusal of these lines may lead any such to enter upon investigations which may, possibly, prove as profitable to the potting industry as they will, undoubtedly, be interesting to the inquirer.

Colours may be classed under certain heads according as they have to undergo more or less severe fires, and by reason of the distinction between the ovens in which the products are burned the lines of demarkation are perfectly apparent, for although the same oxide may produce the same colour at every temperature, the conditions attending the profitable use of any colorant differ with every variation in mixture or fire.

Colouring matter can be used in either of the following ways :—

- | | | |
|-----------------------------|---|---------------------------|
| (a) In the clay. | } | Biscuit fire. |
| (b) Upon the clay as a dip. | | |
| (c) In the glaze. | } | Glost fire. |
| (d) Under the glaze. | | |
| (e) Upon the glaze. | | Enamel or hard-kiln fire. |

But instead of describing the colours used in each class, it will be more convenient to proceed by dealing with the principal colorants one by one, explaining their behaviour in the presence of other substances and under different circumstances.

Before examining the colouring salts in detail it will be well to notice the requirements of each class of treatment above mentioned, that the mind may be prepared to grasp the conditions which, in each case, the materials will be called upon to fulfil.

Coloured bodies are employed mainly for the cheaper grades of wares, such as jugs, teapots, and the like. Whether used as the main substance or as a dip, matters little as to the colouring matter, except that in the latter case the effect of some oxides in altering the contraction of the clay must be taken into account. Most bodies are now mixed in slip, and, therefore, it will be found more accurate to employ the stain also in slip, adhering, of course, to a definite weight for the pint, just as in the case of clays. If the

amount of stain be not sufficient to allow of this it is well to dilute the oxide with a proportion of flint or stone, which must, of course, be allowed for in the mixing. In staining china bodies regard must be had to the presence of bone, which often exerts a detrimental influence upon colours. The greater fire of the china also renders it more difficult to produce a satisfactory colour. In mixing a coloured body notice should be taken whether, in firing, the ware has a tendency to vitrify on the surface, and the endeavour should be made to maintain the coloured clay, when fired, of as nearly as possible the same porosity or density as the unstained clay. This is, of course, a matter for adjustment, but it does not present any insuperable difficulty.

Coloured glazes are seen at their best when quite transparent and when fused upon a white body. Any undulations in the modelling then give light and shade, and a rich mellow effect is produced. The practice of making black ware by means of a blue glaze upon a brown clay is commended for the sake of cheapness, but the special advantages of both coloured body and coloured glaze are lost.

Several distinct palettes of colours in glazes may be produced from the same colorants by simply altering the constituents of the glaze, but

this alteration is to a great extent dependent upon the composition of the body. Thus it is scarcely possible to obtain an alkaline glaze upon a vitreous body except at an extremely hard fire. In preparing coloured glazes it will be found most satisfactory to add the colouring matter to the fritt and to run this down in saggars rather than upon the fritt kiln. A more perfect incorporation of the colorant is the result, with less probability of disturbing the quality of the glaze.

Under-glaze, or rather glaze-kiln colours, for some of them are best used upon the glaze at glost fire, consist, in the main, of colouring oxides without flux, but containing a proportion of clay or similar material as a diluent. Colours used upon the glaze in hard kiln or enamel kiln must have as an integral part of their composition a flux more or less soft, which shall agree with the glaze upon which it is to be used. The salts used in this flux exert great influence upon the tint of the colour itself, so that an extensive knowledge of the behaviour of each material is necessary.

1. *Colouring agents*.—The following metals, in the form of oxides, are employed as colour producers or chromogens: chromium, iron, manganese, zinc, cobalt, antimony, copper, tin, and nickel. In addition to these oxides there are certain salts of the same metals, as: chromate

of iron, chromate of barium, chromate of lead, chloride of silver, and purple of cassius; while for some colours use is made of earths such as umber and ochre.

Chromium is one of the most valuable of colorants in pottery; it may be used in every class of colour from clay to enamel. In coloured bodies the oxide of chrome will give various tints of green, and by combination with cobalt almost any tone may be produced. The greens, however, are not brilliant, but subdued and greyish. Chrome used in excess is liable to spread through the adjacent white parts of the clay, and for this reason it is not easy to make a strong green dip, but on the other hand this substance exerts little or no softening action upon the clay, and will stand the hardest fire.

In glazes chrome is less satisfactory. The particles refuse to dissolve, but remain suspended and retain their opacity, thus the chief beauty of a coloured glaze is lost. Used in minute proportion some salts, such as the chromate of lead, will impart a pale yellowish green to a glaze, but this cannot be considered a desirable colour.

For under-glaze colours chrome is invaluable; its refractory nature enables it to stand, and the readiness with which it will combine with cobalt permits the colourmaker to produce greens of

every shade. The best of these, however, can only be brought out by the use of a considerable amount of flux, and this causes some uncertainty of tint under repeated fires.

Curiously enough the only available pink for under-glaze use is also made from chrome, or rather from tin under chromic influence. Salvétat found only a half per cent. of oxide of chrome in a sample of pink, and it will be seen on making up any recipe for this colour that a very large quantity of the chrome is washed away in the manufacture. The purity of this pink will depend in a very large measure upon the proper calcination, grinding, and washing of the mixture. With a little cobalt various tints of purples, mauves, and amethysts may be produced, but these colours are always liable to a certain amount of separating action exerted by the glaze. The cobalt is dissolved, the tin only suspended, hence if a slight excess of fire be given the glaze carries a portion of the blue away from the pink. This may to some extent be obviated by a thorough calcination of all the ingredients, but it is never entirely got rid of. Chromium oxide may often be introduced with advantage in the form of a salt such as potassium bichromate or lead chromate, but allowance must of course be made for the other elements thus unavoidably included.

For enamel and hard-kiln greens of all shades chrome is used. With a suitable flux, and darkened or lightened with cobalt or Naples yellow, almost any tint is possible, but usually the painter prefers to mingle these at the point of his pencil, so that his requirements are mainly one good dark green and one light.

Iron is an important and indispensable colouring agent. It is more widely distributed in nature than any other stain, as red clays and yellow marls alike owe their tones to its influence. Some commercial and natural products, such as ruddle, crocus, and rouge, are used by potters. They all owe their colouring power to the presence of ferric oxide, but it is not well to depend upon their purity or uniformity. Ferric oxide is readily made by calcining copperas, ferrous sulphate, at a red heat. For bodies and glaze-kiln work the degree of temperature matters little, but for enamel reds the heat is everything.

Upon clays iron exercises a softening influence in proportion to the amount used, but this can to some extent be obviated by the increased use of kaolin. Even then the body containing much iron will not stand a great fire.

In glazes iron supplies a considerable range of fawns and browns, and even, under the influence

of a reducing flame, the green tones so valued in the Chinese celadons. The brown shades are most favoured by lead glazes, the yellow and green by lime and soda.

For under-glaze colours iron is chiefly valuable in the form of the chromate, which is largely used in most glaze-kiln browns. The darker tones are obtained by the addition of manganese, and the lighter by the employment of zinc and alumina. These more delicate tints are, however, somewhat uncertain, and will not stand severe or repeated fires. Ferric oxide is sometimes added to yellow base to produce orange, but this is not a colour in general use, inasmuch as the majority of under-glaze colours are now required mainly for printing. An under-glaze red seems to be, under modern conditions, out of the question. The pure red found upon Rhodian ware was made with a natural clay under an alkaline glaze; the brilliant colour, even if the earth could now be found, would be utterly destroyed by lead.

In the enamel kiln palette iron is extensively used. Reds of all shades are obtained by calcining copperas at different temperatures. Salvétat gives eight distinct tints, ranging from orange-red to deep violet, which are all dependent absolutely upon the heat employed. These colours are not fritted, but the oxide, being obtained of the right

tone, and being thoroughly washed with boiling water to remove every trace of unaltered sulphate, is ground with a sufficient amount of the proper flux. The chestnut-brown from iron chromate may also be obtained in the enamel kiln, and the strong colorant may be modified by the use of zinc oxide. In this case the whole colour must be fritted at a gentle heat.

Manganese is constantly employed in the production of dark browns at every degree of heat. In bodies it is most useful, and is sometimes found in such materials as umber, where its influence is utilised without recognition.

Manganese is mainly used in the form of black oxide, and this almost always contains some proportion of iron. The iron is not objectionable, but the percentage contained should always be ascertained in order to secure the repetition of any desired tone.

In glazes the most remarkable feature of this colorant is that it supplies, in the presence of alkalies, purple and claret tints. To obtain these the absence of both lead and iron is imperative, and hence the carbonate of manganese is the most suitable salt for the purpose, being more generally free from iron than the oxide. To obtain the required conditions is not easy, but upon such soft earthenwares as those of Japan,

which are glazed with silicates of soda and lime, beautiful manganese purples are found, and M. Deck of Paris was very successful in the same direction.

Browns for printing under-glaze are largely dependent upon manganese for their strength and uniformity under varying fires. Iron is used as already explained, mainly as chromate, but manganese is the great resource of the maker of printing browns. To enamel-kiln browns the same remarks apply, except that the necessity for the use of a strong colorant is not so apparent.

Oxide of zinc is colourless, and is not much used for any work at high temperatures. It has already been mentioned in connection with iron browns, and will be touched upon again under cobalt. It is valued on account of the mellowing influence it exerts upon other oxides.

Oxide of cobalt is the most widely known and the most universally used of all metallic colorants. Absolutely indestructible by fire, it supplies the blue tints of the potter's palette from top to bottom. In clays it must be employed with caution, as it exerts a softening influence, but in moderation it may be relied upon to produce almost any shade of purplish blue. In glazes cobalt gives rich if somewhat monotonous effects,

as it dissolves readily in the glaze substance, and the result is a rich transparent blue. Carbonate of barytes has the effect of enriching this blue, but is sometimes productive of other evils. In under-glaze printing and groundlaying cobalt is widely used. Blues of all strengths are supplied by it from the famous *bleu du Roi* to the simple "Brosely" and cheap "flow blue". Combined with alumina it produces mat blue, and it can, moreover, be combined with greens, pinks, and browns in every possible way.

Enamel blues are mainly produced from cobalt with the aid of oxide of zinc, which has the effect of both softening and brightening the colour. The French chemists state that cobalt and alumina can be precipitated together to give an ultramarine colour, but though this appears very beautiful in powder, there is extreme difficulty in fluxing it satisfactorily. Nothing is easier than to make a blue from cobalt, few things are harder than to make a good one and to use it without loss.

Oxide of antimony is colourless in itself, but is valuable in combination with lead. The antimoniate of lead (Naples yellow), used sometimes in combination with oxide of tin, is the foundation of the majority of pottery yellows. This is not used, however, in clay work, and though a good under-glaze yellow is not readily made, nor, in-

deed, greatly wanted, the yellow base, fluxed for the hard kiln or enamel kiln, gives a variety of tints. Oxide of iron can be added to the lead and antimony to produce orange, or the yellow may be used with chrome for making light greens. All these finer tints are in demand when under-glaze painting is in progress, but for printing stronger colours are preferable.

Raised paste for use under gold is also made from this base, the tin giving sufficient body for the purpose.

Oxide of copper is a substance which, under clever management, yields wonderful results, but in body mixing it is practically useless. It will not stand a great heat, and, besides, acts upon clay as a flux. Neither can it be used to any great advantage in under-glaze colours, but for the coloration of glazes a great variety of tints are obtainable. With an ordinary lead mixture copper will afford greens of varying tone and strength. With alkalies a rich turquoise blue glaze can be made. This colour was, it is said, discovered in ancient times, when it was produced by heating a mixture of sand, carbonate of soda, and copper filings. A French chemist has, however, shown that it may also be made without soda, for he succeeded in obtaining a fine blue from sand, lime, and copper. Boracic acid seems to destroy the

fine blue tones and the extreme difficulty of satisfactorily glazing English wares with soda alone accounts for the non-appearance of the fine colour in this country. The glaze made by Deck, and already mentioned as developing the purple tones of manganese, was capable also of giving a fine turquoise with copper. Oxide of copper also supplies, under the influence of a reducing flame, the wonderful red colour or glaze known as *sang de bœuf*. For this it would appear that a felspathic or alkaline glaze mixture is also necessary, for any lead would be reduced at the same time as the copper. The general opinion is that the red colour is caused by finely-divided particles of metallic copper being distributed through the glaze.

At the enamel fire copper is used for the manufacture of cheap simple greens, which possess great transparency, but here also the great value of this colorant is found in the turquoise blues, of which it is the only possible source. The finest turquoise is considered to be that produced on the soft paste of Sèvres. Many attempts have been made to rival this colour, but so far without success. It would seem impossible to construct an enamel colour without lead, and yet every particle of lead is so much loss to the purity of tint in the turquoise.

Oxide of tin is of use mainly in the enamel kiln for the production of white enamels. These owe their opacity to the fact that the white oxide is not dissolved but only suspended in the flux. In making enamel the main difficulty is to secure a pure brilliant white. The least particle of iron is fatal, and the tin itself sometimes assumes a pink cast, apparently without reason. The preparation of the oxide has a great deal to do with its fitness for use in enamel. It is far better made by calcining pure tin in a current of air than by the simpler method of digestion in nitric acid.

Oxide of nickel is more employed in coloured bodies than in glazes or colours, but its chief advantage lies in the fact that it is cheap and can be simply used. In glazes it is liable to cause cloudy separations, and in every case the tones which it supplies are dull and uncertain. Nickel is rarely used in enamel colours.

2. *Colour making*.—For the stains used in coloured bodies or dips there is not much “making” in the sense of manipulation. The important point is to see that the mixture of clays is not destroyed in its nature by the addition of colour. If natural colorants can be procured of good and uniform quality it is often better to employ them, as, for example, good marl cannot be surpassed as

a stain for yellow or cane-coloured clay, but this is a somewhat exceptional case, in that the supply of marl is abundant and the colour very uniform. Where several oxides are used together in the production of a stain, it is best to mix them well and to calcine the whole at a heat at least as great as the finished body will have to undergo. The mass may then be thoroughly ground and mixed with the clay.

Many metallic oxides, in the cross combinations brought about by heat, resolve themselves into partially soluble salts. These should always be removed by washing with hot water until nothing but pure water comes off. This washing may, of course, have the effect of altering the expected tint of the colour, but it is the only way to secure purity and uniformity. It is most important for the maker of tints to be able to match them again accurately, and for this reason no material or process should be relied upon that cannot be adopted a second time. These remarks apply with even greater force to the maker of under-glaze and enamel colours.

The use of coloured glazes is not so extensive as it once was, a fact which must be regretted by all who value the special qualities of ceramic colours. Probably the keen demand for uniformity has contributed to the disparagement of

tinted glaze, for the accidental irregularities which are so attractive to the artistic eye, constitute a fatal objection in the opinion of a certain section of the public.

When possible the stains for coloured glazes should be fritted with a portion of the glaze mixture or of the fritt which enters into it. This fritting is best accomplished in flinted saggars or crucibles at a special heat. The more fusible numbers of the "Seeger" pyrometric cones will serve admirably to record the temperature at which any fritt will melt, and this point should be rigidly adhered to if a repetition of the result be desired. If coloured glazes are to be dipped, it is best not to fritt the whole mass, but to reserve certain parts of the insoluble materials to be ground with the fritt, and thus to assist in the working both at the mill and in the dipping-house.

Under-glaze colours are not difficult to make if the right glaze is at hand. It must be remembered that in the glaze kiln one flux—the glaze itself—has to serve for each and every colour, and, therefore, the modifications that give rise to variation of tint must be made in the colour itself.

Too much stress cannot be laid upon the importance of calcining, grinding, and washing. With pure materials and due attention to these

points success may be attained by any intelligent worker, but there is no room for inattention to any single detail.

Regard must, of course, be had to the purpose for which the colour is to be used. At the present day nine-tenths of the under-glaze colours in use are required for printing, and this demands special qualities. Printing colours must be solid and rich, somewhat opaque and not liable to fade away in the lighter parts. The printing-press can make no allowance for the weakness of any colour, and, therefore, the maker of the colour must eliminate the weakness. For grounds the principal glaze-kiln colour is mazarine blue, which is, generally, almost pure oxide of cobalt. For the advantage gained in working it is best, however, to manipulate the colour by calcining with a proportion of hard flux, afterwards grinding and washing the mixture.

Hard-kiln and enamel colours, if they are to be produced in their full beauty, tax the skill and patience of the colourmaker to the utmost. Foremost amongst these stand the gold colours, mazarine, ruby, carmine, purple, and rose colour. The base of all these is "Purple of Cassius," a rich coloured precipitate of gold thrown down by tin. The difference of tint and shade in the colours is a matter of the amount and character of flux

and of the addition of more or less chloride of silver.

The success of these colours hinges entirely upon details of manipulation. The makers who supply the markets of the world have the experience of many years behind them, and it may be doubted whether, even if their recipes were made public property, any one else could at once obtain as good results.

Briefly, the procedure followed is something like this. A given weight of brown gold is dissolved in *aqua regia* (nitro-hydrochloric acid), and the proper proportion of pure tin is also dissolved, either by slowly adding it to the gold solution or by taking it up with additional acid. The two solutions are then mingled, and the precipitate is thrown down by the addition of large quantities of water. The crimson colour is then collected and fluxed, of course without being fritted, to produce the required colour. This is admittedly a very crude description of the process, but it is enough to indicate the difficulties lying in the path of the inquirer. Let difficulties deter no man, however, for there is a sure market for fine gold colours.

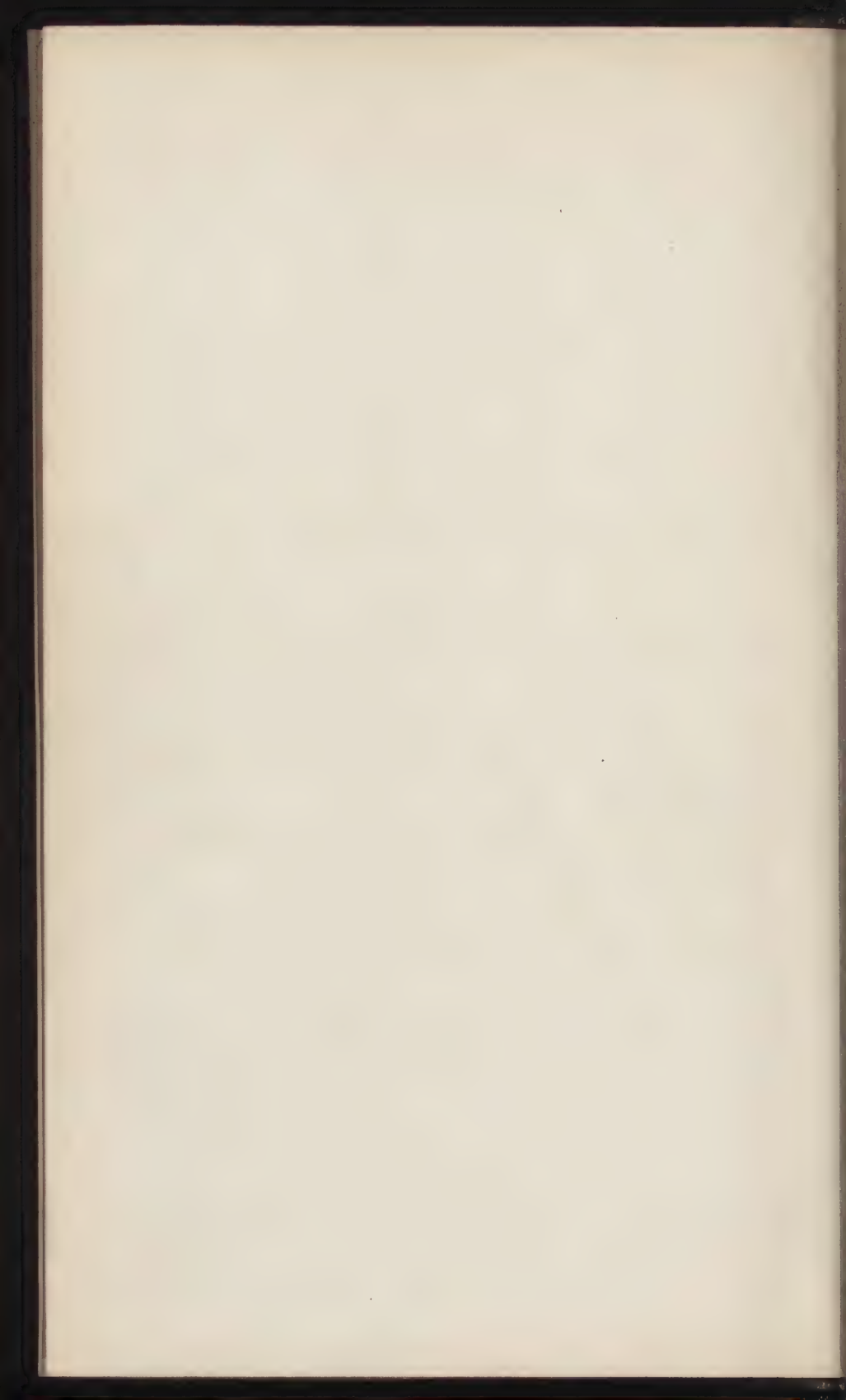
Enamel reds are also colours which need delicate treatment. It has already been explained under the head of "Iron" that the colour is produced by the calcination of copperas. This

should not be trusted to a kiln fire, but should be accomplished in the laboratory, over a clear fire, upon an iron plate. The difficulty is to keep the whole of the salt at one temperature, for some is likely to be over-roasted while parts are yet green. The washing water should be retained, as it may be evaporated to recover the dissolved iron, or the floating hydrate may be collected and employed. Reds are not fritted with the flux, but simply ground for use.

In most other colours the flux and base are melted together, and in this case the chief difficulties lie—first in the preparation of the base, and secondly in the selection of a flux.

A very great similarity exists between glaze-kiln colours and enamel-kiln bases. Any of the former would, if fluxed, produce some sort of a colour in the enamel kiln. But owing to the greater delicacy of the enamel fire a greater range of tints is possible. The manipulative processes are, however, much the same. Calcining, grinding, and washing are the important points, and these should be carefully attended to before the flux be added at all. It may seem useless labour to grind and wash a substance that has to be calcined and ground over again, but the extra work will be abundantly repaid by the superior quality of the resulting colour. The last grinding

should be as perfect as possible. The colour should be reduced to an impalpable powder, and the subsequent drying must be managed with very gentle heat. Few things are more aggravating than to have the working properties of a fine colour destroyed by careless drying. Every particle of the colour should be so soft that it can be pulverised between finger and thumb, and if this be the case a sieve will reduce the whole to the condition beloved of the artist.



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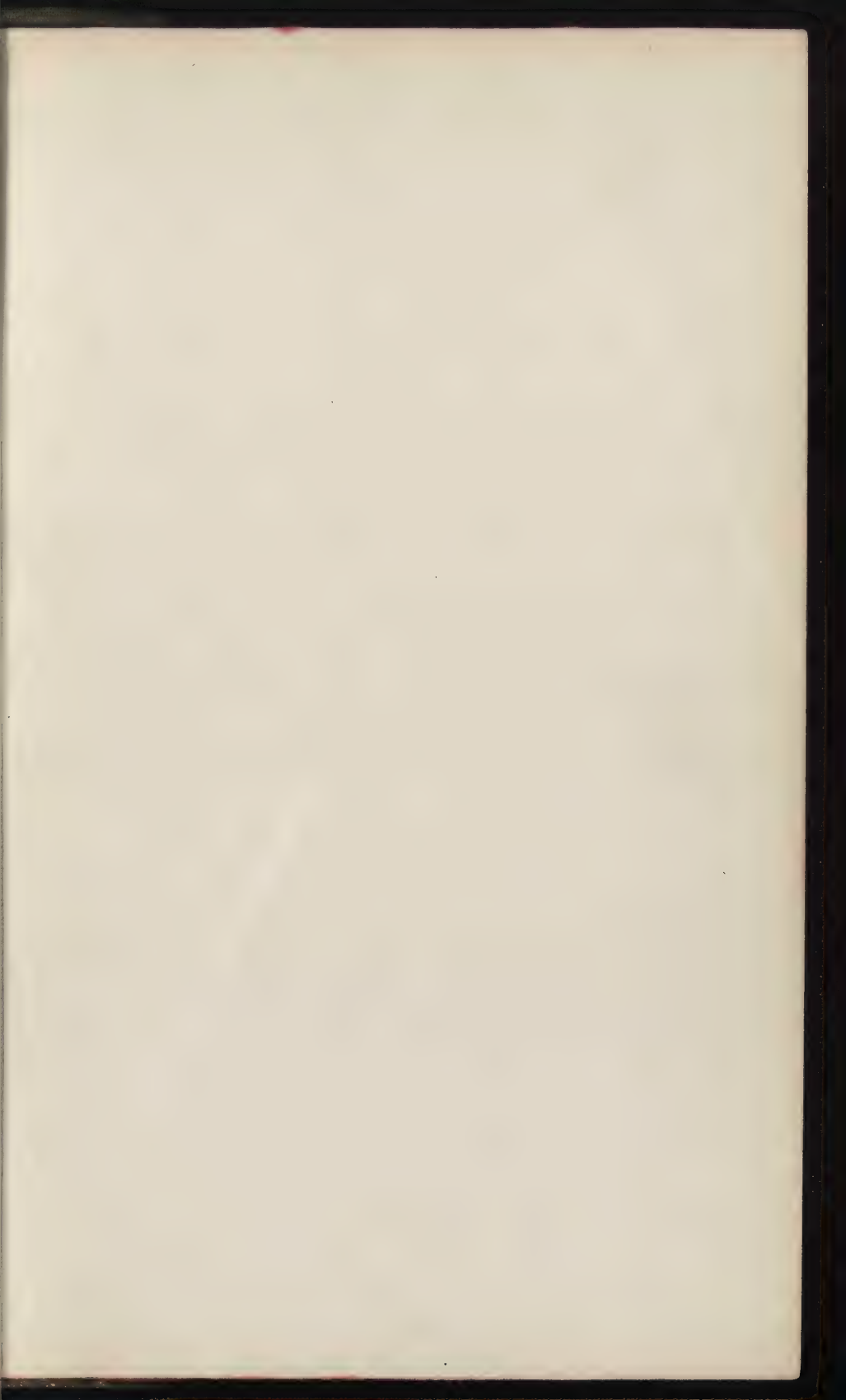
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